POWERFUL CONNECTIONS

PRIORITIES AND DIRECTIONS IN ENERGY SCIENCE AND TECHNOLOGY IN CANADA

The Report of the
National Advisory Panel on
Sustainable Energy
Science and Technology

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PREFACE FROM THE PANEL CHAIR

Dear Minister Lunn

Canadians have reason to be optimistic about our nation's energy future.

As a nation we are blessed with energy resources which are extraordinary in their variety and scale. Canada is a large producer, intensive user, and a major exporter of energy-rich commodities and manufactured products. How skillfully we manage the evolution and future development of our energy economy will, in the long term, have a profound impact on the quality of the lives of Canadians.

Only the continuing vigorous development of energy technologies that will provide us with real future options in how we produce, transform and ultimately use energy can assure us of the ability to respond to the evolving economic conditions, environmental imperatives and the values and expectations of Canadians. This is central to our future well being.

We have provided recommendations in this report that identify technological areas where Canada should focus its investments. We have also proposed some different approaches your government might use as it organizes for and provides support to the priority programs. Here, our focus has been on how best to encourage the development, and support the widespread commercial deployment of transformative technologies.

Of great importance is the need to increase substantially the investments of both our private and public sectors in energy science and technology with programs that recognize the importance of long-term commitments. Short-term, discontinuous measures will fail to attract, develop and hold the talented, highly-skilled manpower upon which our future success ultimately depends.

Your Panel is confident that clear action now to stimulate expansion of our energy science and technology capacity and activity will assure Canadians of future energy choices and of a leadership role amongst nations.

Sincerely,

Angus Bruneau
Chairman

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INTRODUCTION AND SUMMARY OF KEY RECOMMENDATIONS

INTRODUCTION

This report is a call to mobilize a major, long-term Canadian effort in sustainable energy science and technology.

Canada's enormous wealth of energy resources is and will remain a key element of our prosperity and a major geopolitical advantage for the country. However, this wealth has made us complacent: It has masked major vulnerabilities that must be addressed, and unique opportunities that must be realized if Canadians are to reap the full benefits of their energy endowment in the years to come. A major effort to develop new energy technologies and new methods for fostering their development and application in Canada will be critical to achieving this goal and determining our energy future. These technologies will enable us to become world leaders in the responsible, efficient production and use of energy.

Without strong, concerted action on energy S&T, the threats faced by our energy sector could have a major impact on the Canadian economy. First, we are likely moving into a period of sustained higher energy prices. For Canada, higher prices mean greater returns from our energy production, but at the same time, energy consuming sectors of the economy, including the energy sector itself, will face much higher costs. Innovations to reduce the cost of energy production and increase energy efficiency could greatly improve the competitiveness of the economy and benefit the Canadian public who also face higher energy prices.

Second, without a stronger emphasis on energy innovation in this country, we will increasingly rely on technologies developed by others to access our own resources and will depend on others for technological breakthroughs in energy production and use. Importantly, many of our raw energy resources will increasingly be upgraded to high-value products outside Canada. In other words, we risk becoming a branch plant economy in the energy sector known primarily for our raw resources rather than our ingenuity. A focused effort on S&T will allow us to leverage our resource wealth to create a more knowledge-intensive energy sector that can maximize the benefits of our resources for Canadians and export more Canadian-made technologies and expertise to the rest of the world.

Perhaps most importantly, Canada's energy sector faces growing concerns about the environmental effects of energy production and use. These concerns must be addressed—largely through technological innovation—both to protect the environment and to ensure that our energy sector can compete and excel in a global marketplace that, over time, will surely become even more demanding of environmental performance. Important environmental issues include the impacts of energy industries on land, water and air quality, and perhaps most notably, climate change from the emission of greenhouse gases (GHGs). Climate change is a global environmental issue that will have a major impact on the energy sector, given that energy production and use are the main contributors to the growth in GHG emissions. Minimizing greenhouse gas emissions is a long-term challenge requiring the development of transformative energy technologies.

We must deal with these issues through a major effort in energy S&T if we are to ensure the long-term growth and sustainability of Canada's energy economy. Fortunately, we are well positioned to take up the task. The large energy revenues being realized today by Canadian industry and governments provide the financial resources that must be re-invested in the sector to realize much greater benefits in the future. Within our existing energy industries, we also possess significant intellectual and industrial capacity in energy technology. By building on this capacity, we can develop world-leading expertise in areas of Canadian opportunity.

If Canadians invest in, focus on and better coordinate the efforts of our energy innovation system, we will not only address our challenges, but turn them into major opportunities. Science and technology initiatives that meet the major challenges to the energy sector will allow us to lead the world in the development of cleaner, more efficient energy technologies, increase the efficiency and value of our energy-intensive industries, optimize the production and use of our vast portfolio of energy resources, and improve economic and environmental outcomes for the Canadian public. Given our potential, this is a challenge we cannot afford to ignore.

In the following chapters, the Panel outlines what we feel should be the key building blocks of a major Canadian effort in energy S&T. In particular, as per our mandate, we provide recommendations on delivery mechanisms, and we also discuss levels of funding that will promote Canadian leadership in energy S&T and in the global energy economy. We also identify areas of Canadian advantage where concerted public and private sector action on S&T will enable Canada to determine its energy future.

In its deliberations, the Panel viewed the Canadian energy economy as an interconnected system, containing large flows and conversions of energy, strong interdependencies between producers and users of energy, and significant exports. A depiction of this system is presented on page 76 of this report. In recognition of this, our assessment takes a systems approach to energy technology and to the energy innovation system, which is described in detail in Chapter 3.

Should Canadians adopt the recommendations we have developed throughout this report, our country will be well positioned to identify key energy opportunities and work collectively to address them, thereby realizing our full potential.

SUMMARY OF KEY RECOMMENDATIONS

FUNDING AND DELIVERY OF ENERGY S&T

The following recommendations address both funding and mechanisms for the delivery of energy S&T. Effective delivery mechanisms are essential to the accomplishment of key national priorities. To be successful, these mechanisms must be supported by a level of funding for energy S&T activities that is commensurate with Canada's energy opportunity.

Successful energy S&T requires a long-term commitment to funding.

- There is a need for a long-term commitment (minimum of 10 years) by the public and private sectors to focus on energy S&T and fund it in a sustained manner. This commitment is essential given the long lead times required for technological change in the energy economy, and the need to develop and retain the human capital that underpins energy innovation.

All actors in the energy economy must increase their S&T funding to realize Canada's energy opportunity.

- Given the federal government's essential role in funding and performing energy S&T beyond the time and risk profiles of private sector investment, it should strive to at least double in real terms its investment in energy research and development within the next 10 years.
- Provinces own Canada's energy resources and are therefore beneficiaries of successful energy innovation. Consequently, we challenge the provinces to more than double their relatively small current investment in energy R&D over the next 10 years.
- The private sector is the most important funder and beneficiary of energy S&T. It must increase its level of support significantly if Canada is to reap the benefits of value-added, knowledge-based energy products and technologies. To this end, we recommend that the energy sector double its R&D-to-revenue ratio to an average of 1.5% by 2016, with the long-term objective of matching the Canadian industrial average, which currently stands at 3.8%.

A systems approach is essential to maximizing the benefits of energy technologies and effectively managing energy innovation. This approach should be supported by the data and intellectual capacity needed to analyze energy systems.

- Canada should focus on developing technologies that exploit synergies among its many energy resources in order to maximize their benefit to Canadians. The best way to identify these technology priorities is to use a systems approach to assess the existing and potential connections among our energy resources and their associated technologies.
- We also recommend a systems approach to our support of energy innovation, in which the natural linkages between the various stages of the innovation process are recognized and are significantly strengthened in our supporting programs in order to overcome existing barriers to the development and eventual deployment of commercially viable technologies.
- In line with a systems approach, our energy S&T priority areas should be managed and supported in a manner that recognizes both the linkages between technology areas and the need to focus on long-term goals and objectives. To achieve this, federal program objectives and perhaps even funding decisions in energy priority areas should be set by a cross-sectoral board of experts, with representatives from industry, government and academia, and complemented by other stakeholders where appropriate.
- Within a systems approach, Canada must develop an energy systems research capacity in order to set S&T objectives more effectively and identify needs and opportunities for innovation. To this end, the Panel recommends the creation of a small number of energy systems engineering research programs.
- To improve overall decision-making, there is a need for transparent and reliable data on the activities in the energy sector, including investments in energy S&T. We therefore recommend that an independent group be tasked with collecting, maintaining and making available historical and current data from both the public and private sectors.

Clear market signals and increased support for demonstrations are key to commercializing new energy technologies.

- We urge provincial and federal governments to work together to develop clear and consistent long-term market signals to address environmental issues such as climate change. This action would greatly decrease the risk to industry in deploying existing environmental technologies, and would encourage the development of technologies that could greatly reduce the environmental impacts of energy production and use in the future.
- There is a need for significant additional resources to support commercial-scale demonstration and early-stage deployment projects involving new energy technologies. For novel technologies, it may be necessary to support more than just the first commercial-scale project in order to overcome the risks associated with investing in unfamiliar technologies.

Governments should implement mechanisms that encourage greater innovation by the energy industry.

- In large, commodity-based energy industries, governments should consider using regulation or financial incentives to stimulate private sector funding for research to address common, long-term economic and environmental issues.
- The federal government should provide $30 million to leverage investment in a reputable and visionary private sector Canadian venture capital fund focused on energy technologies. Such a strategic investment should be made on a recurring basis to support the ongoing development and growth of innovative, knowledge-based Canadian energy technology companies.
- We strongly support the recommendations of the Canadian Task Force on Early Stage Funding, which would help to foster the development of new energy technology companies and increased energy technology investment in Canada.

There is need for greater focus on energy in federal labs and in academic research.

- Federal energy research labs should conduct a systematic review of their mission, roles and objectives in the context of a federal energy strategy. They should then undergo a review of their activities, by external peers among others, to evaluate their ability to deliver on these goals and objectives, and to assess the effectiveness of existing structures and programs in advancing an energy strategy.
- Dedicated research funds for the support of key national energy S&T objectives should be made available to performers of basic and applied energy research. Public funds should also be targeted to promising yet speculative avenues for long-term research, including:
  - materials science and nanotechnology research for the development of high-efficiency solar photovoltaic materials;
  - improved chemistry and materials for advanced fuel cells;
  - research into novel approaches to hydrogen production and portable storage; and
  - methane gas hydrates.

DEFINING ENERGY S&T PRIORITIES

The other major component of our mandate was the identification of key priorities for sustainable energy S&T in Canada. In our view, high-priority areas for energy S&T are those where focused effort can address both public and private sector imperatives to achieve significantly greater benefits for Canadians. Furthermore, we have taken our sustainability mandate to mean the balancing and, where possible, the simultaneous pursuit of positive economic, environmental and social outcomes. The highest priority was given to S&T options that simultaneously address these three dimensions while providing an opportunity for Canada to become a world leader in selected areas of energy innovation. The priority areas identified are as follows:

Bioenergy

Canada has large waste biomass resources and is a leader in a number of bioenergy-related technologies that could be further developed for domestic and international markets. Beyond waste biomass, authoritative life-cycle analyses should be conducted to examine the economic and environmental merits of different feedstocks and technology options.

Gasification

Given our resource base, the development of world-class expertise in the gasification of carbon-based fuels, including biomass, is a high-priority opportunity for Canada. If coupled with CO_2 capture and storage, these technologies will also significantly reduce the environmental footprint of fossil fuel industries.

CO_2 Capture and Storage

Canada is fortunate to have geologically favourable conditions for storing large amounts of CO_2 near its fossil fuel resources in western Canada. Therefore, there is an opportunity to develop CO_2 capture and storage technologies to increase the environmental sustainability of these important resources. Capture and storage should be strongly linked to government participation in a fossil-fuel gasification effort.

Electricity Transmission, Distribution and Storage

We believe that making the best use of Canada's wealth of electricity-generating resources will require a focus on developing and deploying technologies to optimize electricity transmission, distribution and storage. Unique Canadian challenges brought on by a combination of issues associated with infrastructure, the intermittency of renewable sources, impacts of weather and increasing expectations for quality power, to name but a few, must be addressed. Doing so would increase the benefits derived from existing electricity resources and greatly improve the grid access for a variety of emerging energy options. This is an important technology area in which Canada can build on a strong existing base of expertise. A critical element for success in this area will be stronger cooperation and coordination among the provinces and the federal government in the planning, R&D and deployment of electricity transmission, distribution and storage technologies.

Fuel Cells

Canada has a world-leading position in many fuel cell technologies, due in large part to first-class expertise operating within a strong and vibrant innovative cluster of companies and institutions. Retaining and further extending our leadership position in this knowledge-based sector is critical if we are to capitalize on this increasingly competitive and growing market.

Applied Social Science

There are often many barriers to the development and deployment of new and innovative end-use technologies, with social barriers frequently being as compelling as technical and economic ones. A better understanding of these social considerations would help improve the likelihood of implementing new energy technologies, guide policy development and assist in better energy S&T program delivery. We recommend that a major research program be launched in applied social science, aimed at better understanding individuals' and organizations' decisions on energy-related end-use technology purchases and on their subsequent use patterns.

Additional Recommendations

In addition to identifying a small set of key priority areas, we have made important observations relating to many of the other technology areas we considered during our deliberations. Discussions and recommendations relating to each technology area are provided in the body of the report.

CHAPTER 2

FUNDING OF CANADIAN ENERGY S&T

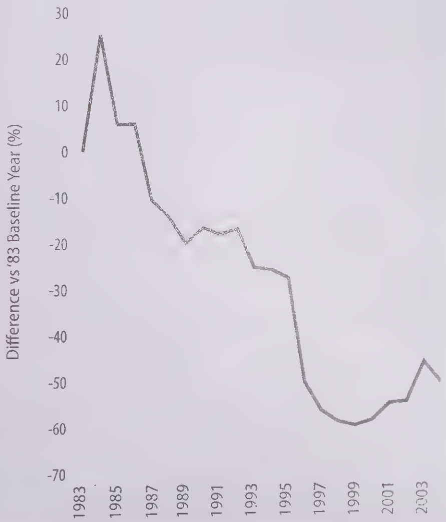
As a first step towards Canada becoming a global energy leader, the Panel argues for a long-term commitment to increased funding for energy S&T by all participants in the Canadian energy economy.

THE IMPORTANCE OF A LONG-TERM COMMITMENT TO FUNDING

> **RECOMMENDATION:** There is a need for a long-term commitment (minimum of 10 years) by the public and private sectors to focus on energy S&T and fund it in a sustained manner. This commitment is essential given the long lead times required for technological change in the energy economy, and the need to develop and retain the human capital that underpins energy innovation.

Canadian leadership in energy S&T will require the development and retention of a critical mass of highly skilled researchers and other workers. This will happen only if there are reasonable expectations that the resources needed to support their efforts will continue to be available in Canada throughout their careers. In addition, taking a promising idea from the laboratory to market is frequently a long and arduous process. Even when a commercially viable technology exists, it can take decades to adapt and deploy it widely in the marketplace. This is particularly true when a technology replaces existing long-lived energy infrastructure.

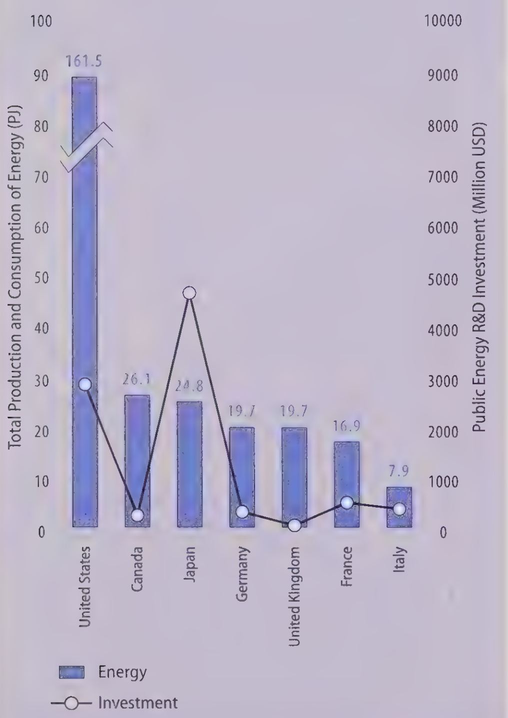
FIGURE 1.
Federal Investment in Energy R&D



These realities underlie the need for a sustained commitment to supporting energy S&T over periods of time that are considerably longer than the typical electoral cycle. In the past, investments in energy S&T have fluctuated wildly; for example, federal funding has dropped steeply over the past 25 years (see Figure 1), despite the fact that energy has consistently been an extremely important part of the Canadian economy. This clearly has to change for Canada to realize its energy opportunity. Becoming a global energy leader will require a strong ongoing commitment from governments and the private sector to fund and take an active role in a national energy S&T effort.

THE IMPORTANCE OF INCREASED FUNDING FOR ENERGY S&T

FIGURE 2.
Comparison of energy production, consumption and public energy R&D investment among G7 countries, 2003



Together with this long-term commitment, a substantially higher level of investment in energy S&T is needed for Canada to become a leader in the global energy economy. Relative to other developed nations, the importance of the energy sector in Canada is high, as reflected by our total energy production and use. As illustrated in Figure 2, of all the G7 countries, only the US produces and consumes more energy than Canada. This situation is driven by Canada's energy wealth, which supports our energy-intensive industries while leaving room for considerable energy exports. However, total public sector energy R&D investments in Canada lag behind those of Japan, the United States, France and Germany. As a result, these countries are forging ahead in some sectors and creating a technological advantage that can give them an edge in future energy markets.

Canada must recognize the long-term value of its energy S&T investments. Existing investments make up a disproportionately small fraction of the enormous private and public revenues realized from the development and use of our energy resources. We therefore believe that a much greater re-investment of energy revenues into energy S&T is both achievable, needed and will reap substantial future benefits. This investment must come from federal and provincial governments and, most importantly, the private sector.

RECOMMENDATION: **Given the federal government's essential role in funding and performing energy S&T beyond the time and risk profiles of private sector investment, it should strive to at least double in real terms its investment in energy research and development within the next 10 years.**

For Canada to become a world leader in sustainable energy production and use, increased federal government investment is needed to foster long-term research and innovation, much of which is typically beyond the scope of private sector investment. Despite the greater opportunities and challenges we have before us today in a much larger Canadian energy economy, the federal investment in energy R&D is less than 40% of its peak levels of the early 1980s. Overall, we feel that there is a need for much stronger government investment. We suggest that resources be increased to achieve at least a doubling over the next 10 years. This increase should be at a rate that corresponds to our ability to use the funds effectively. This will enable the federal government to build on experience and to develop greater capacity within the Canadian energy innovation system over time. By significantly increasing its energy S&T activities, the federal government would also be sending a strong message to both the provinces and the private sector that more efforts are required by all participants.

RECOMMENDATION: **Provinces own Canada's energy resources and are therefore beneficiaries of successful energy innovation. Consequently, we challenge the provinces to more than double their relatively small current investment in energy R&D over the next 10 years.**

The provinces own most of Canada's energy resources, and energy-intensive industries are important components of many provincial economies. As a result, provincial governments benefit economically from successful new energy technologies. They also have a responsibility to ensure sound stewardship of their energy resources and the environment, objectives that are facilitated by energy technologies. In total, the provinces

currently spend roughly $50 million per year on energy R&D (see Figure 3), which is roughly 20% of the federal government investment and only a very small fraction of provincial revenues from the energy-related sectors (see Figure 4). Given these figures, there is a strong case for the provinces to increase their investments in energy R&D by a factor considerably greater than that of the federal government.

FIGURE 3.
Canadian Energy R&D Funding History

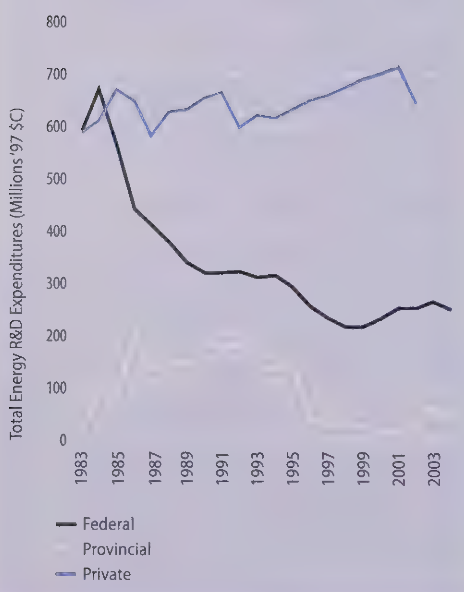
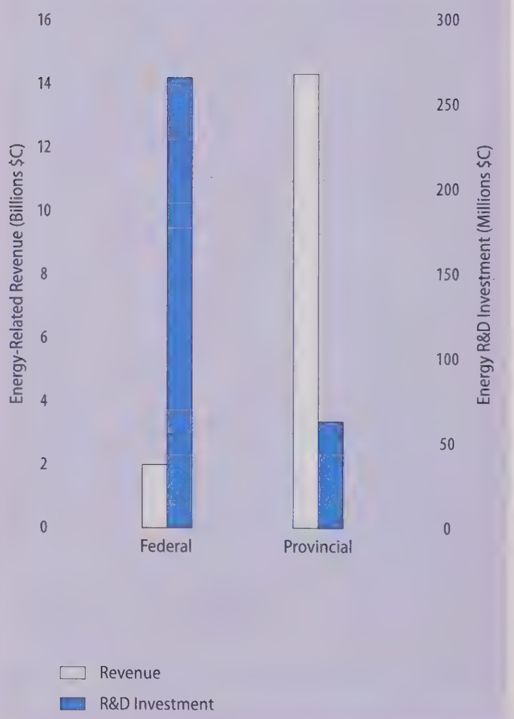


FIGURE 4.
Energy-Related Revenues & R&D Investments 2003

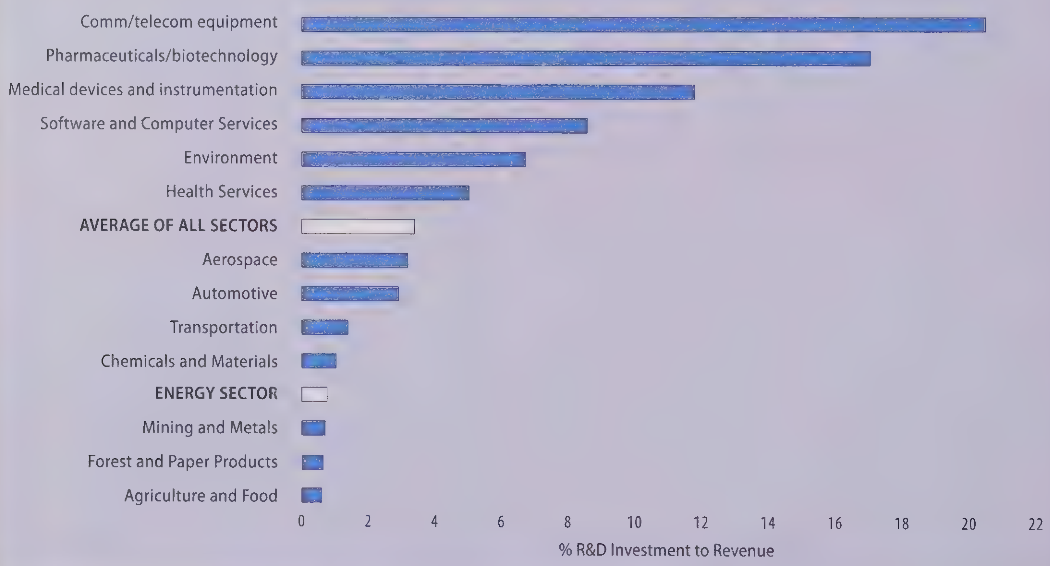


RECOMMENDATION: **The private sector is the most important funder and beneficiary of energy S&T. It must increase its level of support significantly if Canada is to reap the benefits of value-added, knowledge-based energy products and technologies. To this end, we recommend that the energy sector double its R&D-to-revenue ratio to an average of 1.5% by 2016, with the long-term objective of matching the Canadian industrial average, which currently stands at 3.8%.**

Realizing Canada's potential will require the financial and intellectual leadership of the energy industry, and a shift in emphasis towards value-added and knowledge-based outputs. While governments can help to stimulate energy R&D, it is the energy industry that must assume leadership in a national effort to become a global energy leader. The private sector can best guide and fund the development of new energy technologies that will meet the needs of energy producers and users. It also stands to gain much by realizing Canada's energy opportunities. Without the active participation of the energy industry, additional government funding for energy R&D will have little impact.

Industry is the largest investor in energy R&D in Canada, spending more than $700 million annually. Nevertheless, we note that overall private sector R&D spending as a percentage of its energy revenues is only 0.75%, less than one fifth of the Canadian industrial average of 3.8% (see Figure 5). Since over $200 million of these R&D expenditures are by the emerging fuel cell industry, whose revenues are still relatively small, it is evident that the major energy industry sectors spend substantially smaller-than-average percentages of their revenues on energy R&D.

FIGURE 5.
Private Sector Research Spending Intensity – 2003



The conventional wisdom is that low research intensity is in the nature of the energy sector, as its final outputs are most often commodities rather than new "knowledge-based" products that require intensive research and development. Furthermore, much of the innovation needed to improve the economic and environmental outcomes of energy production and use is embedded in the equipment purchased by energy producers and users. This third-party innovation does not show up in energy R&D statistics. Today, much of the new equipment used in Canada is developed by foreign suppliers.

This view must change in order to realize the opportunity we have before us. With a greater effort, Canadians can develop the technologies and expertise to increase the value of our energy resources while lowering their environmental footprint and production costs. In addition, only a new, knowledge-intensive approach to energy innovation will help us to compete in supplying a rapidly increasing global demand for more efficient, environmentally responsible energy technologies, assuring maximum benefits to Canadians over the long term.

To achieve these goals, the private sector must be willing to commit substantially greater resources. A doubling of its R&D intensity to 1.5% of revenues by 2016, with the ultimate objective of matching the Canadian industrial average, would be an appropriate response given the size of the challenge. As part of this effort, multinational firms that participate in the energy sector must be encouraged to perform and source more of their research in Canada. In other priority sectors, Canadian governments have proactively worked with multinational firms to bring major centres of expertise to the country; the same should be true of energy. Along with money must come a greater commitment by the private sector to invest in its human resources in energy R&D. Doing so will create within industry a greater understanding of and demand for new technologies. This in turn will guide and support the creation of a much stronger Canadian energy innovation system.

CHAPTER 3

DELIVERY MECHANISMS FOR ENERGY S&T

Increasing the level of investment in energy S&T is absolutely necessary if Canada is to become a global energy leader, but it is not sufficient to ensure success. Canada must recast its energy innovation system into one that identifies and invests in strategic priorities for energy S&T where it can and should take a leadership role. The Panel has identified priority areas in the chapters that follow.

To be successful in these priority areas, the funding and delivery mechanisms for energy S&T must be re-thought to ensure that they support the accomplishment of key national goals. This chapter presents the Panel's recommendations on how to restructure and improve the energy innovation system in Canada. It begins with general recommendations that apply to all technologies and the entire innovation process, followed by recommendations that are specific to the different stages of innovation.

The recommendations in this chapter seek to improve the setting of priorities, the ability to deliver on priorities, and the ways in which Canadians work together in energy S&T. However, they assume that Canada has the human capital needed to make them a reality. As mentioned in Chapter 2, highly skilled engineers, scientists and trades people are required to make our country an energy leader. Therefore, the development and retention of human capital must be considered an integral component of all our energy S&T efforts.

MECHANISMS ALONG THE INNOVATION PROCESS – THE NEED FOR A SYSTEMS APPROACH TO ENERGY TECHNOLOGY AND ENERGY INNOVATION

RECOMMENDATION: Canada should focus on developing technologies that exploit synergies among its many energy resources in order to maximize their benefit to Canadians. The best way to identify these technology priorities is to use a systems approach to assess the existing and potential connections among our energy resources and their associated technologies.

In general, a systems approach involves defining objectives for the system and then looking at the ways they might be achieved by exploiting potential synergies between elements of the system or by finding new ways to overcome existing barriers. Too often in the energy sector, we look at individual energy resources and their associated technologies in isolation from one another, rather than taking such a systems view. A systems approach would enable us to readily identify those energy technologies that could be developed to maximize the benefits we realize from our varied portfolio of energy resources, energy carriers and end uses of energy.

As a relatively simple example, a systems approach to energy technology can be applied to the electricity system. Sources of electricity generation in a region might include hydro dams, nuclear power plants, coal fired power and wind turbines, each of which has its unique attributes as a source of supply. We recognize that using these sources in appropriate combinations could overcome the weaknesses of each individual source, thereby increasing the reliability of electricity supply and the value of the electricity-generating assets as a whole. A key technology priority within such a system might then be the development of control technologies that employ combinations of electricity sources on the grid in an optimal way. Later in this report, we take such a systems approach to grouping energy technologies and identifying key S&T priorities across the energy economy.

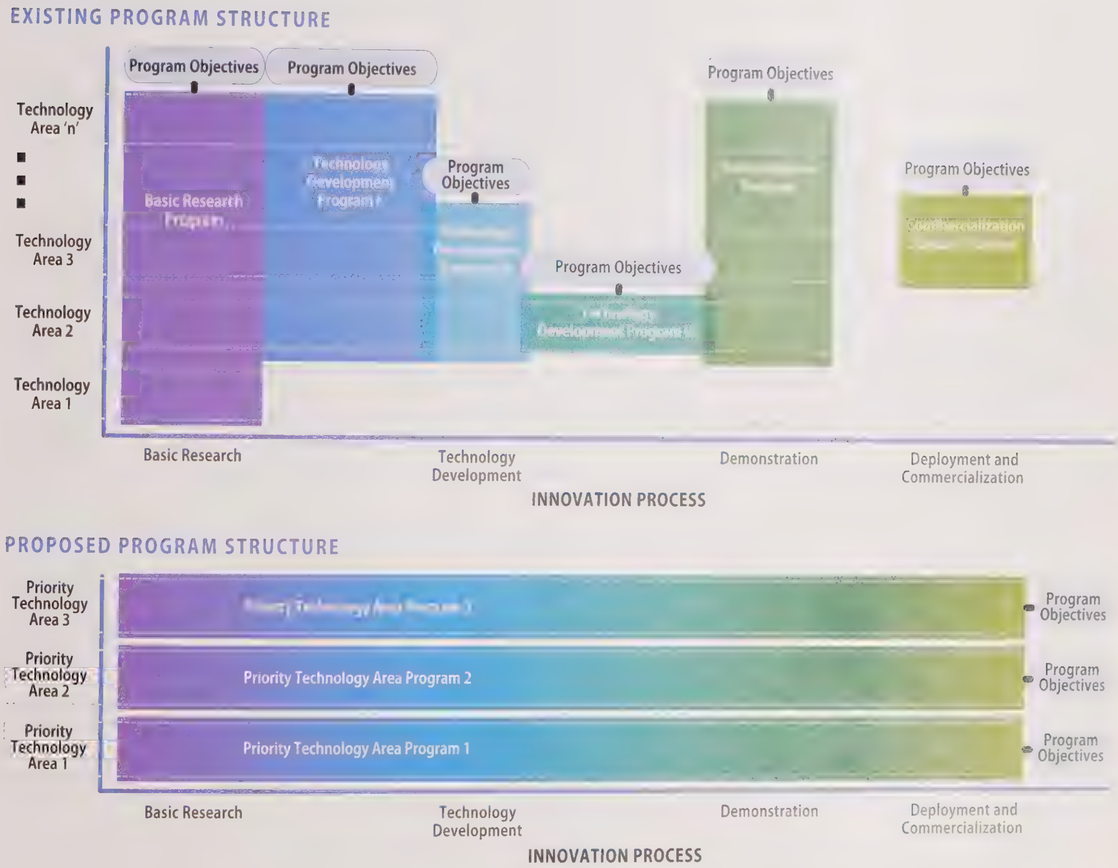
RECOMMENDATION: We also recommend a systems approach to our support of energy innovation, in which the natural linkages between the various stages of the innovation process are recognized in our supporting programs and are significantly strengthened to overcome existing barriers to the development and eventual deployment of commercially viable technologies.

Successful innovation requires the continuous sharing of ideas and issues among those involved in the various stages of technology development and the creation of common objectives to drive the work at each stage. Taking a systems approach to energy innovation lets technology developers both access and encourage the best science to produce technologies that address real-world needs. A systems approach also allows those involved in various stages of technology development to work together to identify and address key barriers that may prevent good science from being turned into successful technologies. Therefore, Canadian leadership in energy S&T will require a streamlined energy innovation system.

RECOMMENDATION: In line with a systems approach, our energy S&T priority areas should be managed and supported in a manner that recognizes both the linkages between technology areas and the need to focus on long-term goals and objectives. To achieve this, federal program objectives and perhaps even funding decisions in energy priority areas should be set by a cross-sectoral board of experts, with representatives from industry, government and academia, and complemented by other stakeholders where appropriate

To support strong linkages among the stages of innovation in each of the priority technology areas identified, investments and efforts should be managed coherently along the entire innovation process. Figure 6 shows a visual representation of our recommended approach compared to the current mode of operation.

FIGURE 6.
Existing and Proposed Energy S&T Program Structures



In managing federal programs, federal government teams should be responsible for understanding the issues within each technology area across the entire innovation process, from research to commercialization. Each team would have the authority to focus resources on priority issues at any stage of technology development. Ideally, the mandate of such teams should focus on the needs of the innovators and not be constrained or complicated by traditional departmental mandates.

The objectives and perhaps even funding decisions that would guide the work within a particular technology area would not be set by the federal government alone, but by a small board of experts from industry, governments and academia, complemented by other stakeholders where appropriate. This board should ensure a balance of short- and long-term initiatives. A key role of the board would be to improve the alignment of federal, provincial and private sector S&T investments and objectives. Doing so would increase the likelihood of meeting S&T objectives in our priority areas.

In essence, this approach is the logical extension of a technology road mapping process. Road maps bring together key stakeholders in a given area to define high-level objectives and issues. Yet it is hard to implement the insights gleaned from road maps in a structure that lacks technology-specific management. A systems approach across the full innovation process in priority technology areas would complement objective setting with the structures and resources needed to deliver tangible results.

A systems approach can also address a number of issues in energy technology funding and management, the two most prominent being:

A plethora of programs and organizations involved in energy S&T.

The existence of too many funding pots from too many organizations leads to considerable confusion and overhead for funding applicants. In addition, some energy technology areas have numerous federal actors involved, with no clear lead group or department. This makes it difficult for both private and public sector deliverers of S&T to identify a point of contact within the federal system for funding good projects. A goal should be to develop a single window for this purpose. Government officials should be commended for their efforts to coordinate the activities of multiple departments and agencies, however, the ultimate measure of success is not interdepartmental coordination, but the development and commercialization of energy technologies. Provinces also have research and funding programs in various technology areas that often work independently of federal programs, further complicating the funding picture. A good example of the involvement of too many actors is the federal government's Hydrogen and Fuel Cells Coordinating Committee, which involves over 30 groups within the federal government that participate in some capacity in the development of hydrogen fuel cells.

Programs that focus on specific niches in the innovation process, rather than on specific technology outcomes.

At present, individual programs frequently cover the full suite of energy technologies but target specific parts of the innovation process, such as basic research, product development or demonstration, the boundaries of which are difficult to define. This approach leads to overlapping program mandates and creates confusion for those seeking funds. Furthermore, funders are not compelled to examine how issues at various stages of technology development interconnect. The result is often a lack of joint priority setting by those involved in different aspects of technology development. In addition, this approach provides little guarantee that once a technology has made it through one stage of development, there will be a government program or private sector receptor at the next stage. We have identified this lack of receptor capacity as a major factor limiting the commercial success of new energy technologies.

Three additional points should be taken into account. First, it is likely that at the commercial end of the innovation process, the important issues have less to do with technology-specific concerns and more to do with marketing and business development. This would suggest that our systems approach would need to accommodate a changing focus once a technology reaches the commercialization stage. Second, a well-balanced portfolio would devote some S&T funding to activities outside key priority areas, to ensure that we maintain the capacity to realign our resources should other areas become more promising over time, and to be responsive to emerging regional challenges and priorities. Third, we recognize that many existing programs have had some success in their fields of influence, and that re-engineering current federal programs to bring them in line with our recommendation would require a substantial effort. Nevertheless, we believe that the benefits of our approach would be substantial enough to warrant a move towards system-based and objective-driven programs than span the full innovation process. In the short term, we encourage efforts to better integrate existing federal programs along the system lines we have described, in order to identify improvements in existing programs and to help develop future S&T initiatives in line with our systems approach.

With these provisos, we believe that the suggested systems approach to energy technology funding and management would have significant advantages over the status quo.

RECOMMENDATION: Within a systems approach, Canada must develop an energy systems research capacity in order to set S&T objectives more effectively and identify needs and opportunities for innovation. To this end, the Panel recommends the creation of a small number of energy systems engineering research programs.

The mandate of these university-based programs should be to:

- identify promising avenues for innovative basic and applied research that could spawn new technologies;
- analyze the technological and public policy dimensions of various energy systems and assess the technical, economic, social and environmental performance of energy technologies;
- identify issues that prevent energy systems from realizing their full economic or environmental potential in both the short and long terms, and suggest system level objectives that provide optimal ways of dealing with these issues;
- build the human capital needed to deliver energy science and technology effectively; and
- support public and private sector decision-making along the innovation process from basic research to ultimate commercial deployment, and bring together public and private sector players to identify and address high-priority issues.

We believe that the necessary focus can best be developed and maintained if single institutions are made accountable for managing and leading these research programs and allocating research funds to worthwhile projects. Lead institutions should be those that demonstrate the greatest capacity to carry out such a program in close collaboration with a broad set of industrial, academic and governmental partners.

Within an energy-systems research effort, there are specific areas that the Panel has identified as being worthy of particular focus in the Canadian context. These are:

- carbon-based fuels, with an emphasis on gasification and carbon dioxide (CO_2) capture and storage
- electricity transmission, distribution and storage
- social science related to energy end use

The rationales for these choices are provided in subsequent chapters of the report.

RECOMMENDATION: To improve overall decision-making, there is a need for transparent and reliable data on the activities in the energy sector, including investments in energy S&T. We therefore recommend that an independent group be tasked with collecting, maintaining and making available historical and current data from both the public and private sectors.

Clear information about the inputs and outputs of energy S&T activities conducted by the public and private sectors is crucial to aligning our resources more effectively in the future. During the preparation of this report, we were struck by how difficult it was to obtain high-quality, detailed data on energy technology initiatives, funding and outcomes from the federal government and from provinces and industry. Having consistent, detailed data that can be disaggregated along system lines and rolled up to give a snapshot of the energy economy would be very valuable when making decisions about where and how funds should be allocated.

In sharp contrast, the United States has a number of organizations focused on providing energy data, most notably the U.S. Energy Information Administration, with a staff of over 350 and an annual budget in the range of US$80 million. We recommend that a group be tasked with collecting and maintaining detailed Canadian energy information that could be made available to both the public and private sectors to inform policy and improve investment decisions in energy technology.

ACTIVITIES WITHIN THE INNOVATION PROCESS

We have argued that the stages of innovation in the energy sector should be more strongly linked and viewed as a connected system. Within this systems approach, each stage of innovation has specific issues and opportunities associated with it, as discussed below. The ultimate goal of the energy innovation system should be to develop technologies that industry will successfully implement in order to address important opportunities and challenges within the energy sector. In line with this perspective, we present our recommendations beginning with those relevant to commercialization and then working backwards through technology development and, finally, to research.

While there are myriad ways to divide the innovation process into stages, the Panel found it useful to work with the following definitions:

- **Research:** Scientific investigations typically carried out in universities and some government labs, including proof of principle and the development of a working prototype. Such early-stage work is typically too risky to be led by the private sector.
- **Technology development:** This stage covers the development of a prototype into a viable product or process and is usually led by the private sector, although government labs may be involved.
- **Demonstration and early-stage deployment:** At these stages, technologies are implemented in real-world situations. However, due to high costs or the perceived risk on the part of potential early buyers of a new technology, public funds may be required to support worthwhile individual projects that will encourage commercially driven implementations of these technologies.
- **Commercialization:** At this fully deployable stage, market and regulatory forces determine the ultimate fate of a new technology.

DEMONSTRATION AND COMMERCIALIZATION OF NEW TECHNOLOGIES

RECOMMENDATION: We urge provincial and federal governments to work together to develop clear and consistent long-term market signals to address environmental issues such as climate change. This action would greatly decrease the risk to industry in deploying existing environmental technologies, and would encourage the development of technologies that could greatly reduce the environmental impacts of energy production and use in the future.

Focused investment in S&T can help to develop new energy technologies. However, investment alone cannot create market pull — the demand for a technological solution that is needed to spur successful innovation and the commercialization of new technologies by the private sector. Technological solutions that improve the economic outcomes of energy producers and consumers are likely to be demanded by the market. In contrast, market pull for cleaner energy technologies is typically driven by government, either through financial incentives to adopt clean technologies or flexible regulation that encourages innovative solutions to environmental problems. Without market pull, technology push in the form of government investment in S&T for environmental technologies will likely be ineffective.

To achieve environmental objectives, governments must issue clear, sustained signals to provide companies with certainty that their efforts to develop and use cleaner technologies will be rewarded over time. This will increase the degree of private sector commitment to innovation. Government signals must, however, recognize the long development times and even longer deployment times of transformative technologies. They must also be consistent with the turnover times for capital investments in energy infrastructure. Furthermore, in providing such signals, governments must make the public aware that addressing environmental objectives frequently entails some economic costs, a fact that the public must be willing to accept.

RECOMMENDATION: There is a need for significant additional resources to support commercial-scale demonstration and early-stage deployment projects involving new energy technologies. For novel technologies, it may be necessary to support more than just the first commercial-scale project in order to overcome the risks perceived in investing in unfamiliar technologies.

Even when there is market pull for a technological solution and a viable solution has been developed, firms may be unwilling to invest due to real or perceived risks regarding the implementation of new technologies. Public support for demonstrations is thus important to mitigate this risk. Demonstration projects should be industry-led, and involve only those technologies that have a high likelihood of success in the marketplace. Overly ambitious "model" projects, attempting to demonstrate too many innovations at once, increase the level of complexity and reduce the likelihood of success. As a result, the technologies demonstrated and expertise gained are less likely to be adopted commercially.

In addition, the first successful commercial implementation of a new technology is often not enough to overcome the risk perceived by others associated with the technology. This is particularly true when a new technology is meant to replace a proven technology that is fundamental to the functioning of a business. Therefore, where warranted, there should be latitude to provide some support to "second movers" in the implementation of a new technology.

ENCOURAGE GREATER INNOVATION BY THE ENERGY INDUSTRY

RECOMMENDATION: **In large, commodity-based energy industries, governments should consider using regulation or financial incentives to stimulate private sector funding for research to address common, long-term economic and environmental issues.**

The level of investment in research is very low in some large commodity-based energy industries. For example, the electricity sector spends only 0.59% of revenues on research, and the oil and gas sectors spend 0.36%. This situation persists despite the fact that such sectors could benefit from collaborative research into longer-term issues of mutual interest. Coupled with this lack of research funding is the rather limited and dwindling human capital devoted to technology issues.

In such sectors, developing methods to generate funding for long-term research to be managed by industry would increase both the financial and human resources devoted to addressing important economic and environmental issues. This approach has proven successful in other jurisdictions. In the U.S., for example, pooled research funding has supported collaborative research by the Electric Power Research Institute and the Gas Technology Institute, both of which have conducted extremely useful work in their respective sectors. Funding could be generated either through regulatory instruments (such as levies on energy users and mandated contributions from energy producers) or by providing public funds to augment voluntary contributions from the energy sector.

RECOMMENDATION: **The federal government should provide $30 million to leverage investment in a reputable and visionary private sector Canadian venture capital fund focused on energy technologies. Such a strategic investment should be made on a recurring basis to support the ongoing development and growth of innovative, knowledge-based Canadian energy technology companies.**

There is a significant opportunity to foster the development of knowledge-intensive energy companies that produce value-added technologies and products for domestic use and export. Key to the development of such companies is improved access to early-stage venture capital. A promising approach is to provide government investment that could stimulate further private sector investment in select energy technology venture capital funds to be run by reputable and visionary private sector venture capital firms.

Government investment should be in the form of a limited partnership, in which the fund's management, acting as general partner, has full authority to select, assume and, if necessary, liquidate investments. In addition, no explicit conditions should be placed on the type of investments permitted, aside from the requirement that they be in the Canadian energy sector. Even without government direction, such funds would by their nature address the public good objectives of promoting vibrant energy technology clusters and developing environmental technologies that can address both Canadian and international opportunities related to energy production, conversion and use. The federal government announced such an approach to seed funding for venture capital in Budget 2004, without specifying a particular sector of focus.

RECOMMENDATION: We strongly support the recommendations of the Canadian Task Force on Early Stage Funding, which would help to foster the development of new energy technology companies and increased energy technology investment in Canada.

Launched in early 2004, the Canadian Task Force on Early Stage Funding has recently tabled a number of recommendations for improving the quantity and quality of venture financing available to firms throughout their life cycle. The Panel strongly supports these recommendations for the energy technology sector, which can be summarized as follows:

- an Innovation and Productivity Tax Credit to encourage the formation of risk capital;

- harmonization of the rules for the Scientific Research and Experimental Development Tax Credit (SRED) or the creation of other means to provide financial support for R&D in small, innovative companies that do not yet have taxable profits, and removal of the requirement to be a Canadian-controlled private company to qualify. The Panel adds that there is a need to assess the effectiveness of the SRED tax credit in promoting incremental private sector research investments in the energy sector; and
- changing the taxation rules to facilitate foreign capital investment in innovative companies.

IMPROVED ENERGY RESEARCH AND DEVELOPMENT

RECOMMENDATION: Federal energy research labs should conduct a systematic review of their mission, roles and objectives in the context of a federal energy strategy. They should then undergo a review of their activities, by external peers among others, to evaluate their ability to deliver on these goals and objectives, and to assess the effectiveness of existing structures and programs in advancing an energy strategy.

The work of federal government energy labs is valuable to the energy innovation system. We note in particular the significant role of Natural Resources Canada's energy research labs (the CANMET Energy Technology Centres), which perform most of the energy S&T in the federal system. Federal labs are required to perform a wide array of important and potentially conflicting functions — including standards setting; conducting in-house, early-stage research and contract work for industry; running S&T funding programs; and providing policy advice to government, all in a very constrained funding environment. This broad set of responsibilities appears to have been acquired piecemeal over time, and the labs have not had the opportunity to develop a coherent framework for clearly defining their objectives, roles and key functions.

To increase the effectiveness of the energy innovation system, it is time to conduct a systematic review of the mission, roles and objectives of federal energy labs within the context of the national energy innovation system. Once this is done, there is scope for an external peer review to assess whether the labs are well positioned to deliver on these objectives, and evaluate the quality of the labs' linkages with the relevant academic, provincial and private sector communities. To the best of our knowledge, federal energy labs have never undergone a structured external review process, which is a valuable assessment and management tool commonly used in other countries.

This review could also assess whether improved organizational structures could help federal labs to better deliver on their mandates, examining for example the value of separating the research, programs and policy functions of the labs, and identifying ways in which the labs could help to further increase the energy technology capacity in the private sector.

RECOMMENDATION: Dedicated research funds for the support of key national energy S&T objectives should be made available to performers of basic and applied energy research. Public funds should also be targeted to promising yet speculative avenues for long-term research, including: materials science and nanotechnology research for the development of high-efficiency solar photovoltaic materials; improved chemistry and materials for advanced fuel cells; research into novel approaches to hydrogen production and portable storage; and methane gas hydrates.

There is a need for greater alignment between the energy technology demands of the marketplace and energy-related research in universities. In large measure, this is due to the lack of objective-based funding to guide research in applied science and engineering faculties, which are the primary source of early-stage applied research for the development of new technologies. We therefore recommend that dedicated, targeted funding be established for basic and applied energy research.

Consistent with the systems approach to energy innovation outlined above, objectives and criteria for funded research might be best defined by a cross-sectoral board of experts within key technology areas. Funds could then be disbursed through conventional channels, such as granting councils.

Funds should also be allocated to speculative areas of energy research which, while not yet priorities, might have major benefits for the energy system of the future. It is important that publicly funded S&T in both universities and research institutes not shy away from high-risk, high-reward areas of early-stage research. This important phase of research is beyond the risk tolerance and timelines of the private sector. The very nature of S&T guarantees that most early-stage efforts will fail, but this should not deter researchers from pursuing promising yet high-risk endeavours. In later sections of this report, we have identified some promising areas for targeted funding of early-stage research, these being:

- materials science and nanotechnology research for the development of high-efficiency solar photovoltaic materials;
- research into improved chemistry and materials for advanced fuel cells;
- research into novel approaches to hydrogen production and portable storage; and
- research into methane gas hydrates.

CHAPTER 4

IDENTIFYING ENERGY S&T PRIORITIES

DEFINING PRIORITIES

Having proposed how the delivery of energy S&T can be improved, we now turn our attention to the second element of our mandate: identifying key priorities for Canadian energy S&T. Following discussions, we agreed on a principle to guide the priority-setting process:

In the Panel's view, in addition to addressing our sustainability mandate, high-priority areas for energy S&T are those where focused effort can address both public and private sector imperatives to achieve significantly greater benefits for Canadians.

In other words, a national set of key priorities should identify areas where public and private interests converge. Priorities defined in this way should encourage a focused effort by all participants in energy innovation in Canada. This will promote the development of technologies that help us make the best use of our energy opportunities in the interests of the Canadian public.

This principle restricts the set of S&T activities that we feel are candidates for a focused national effort. However, it does not mean that other energy S&T activities are not important or should not be supported. For example, it is in the interest of the private sector to invest in new technologies that will address conventional market demands. However, such technologies are likely to be developed without increased public-private cooperation and effort. Likewise, government should be properly resourced to develop standards and codes, to provide a knowledge base from which to assess Canada's energy resources, and to support energy technologies that will improve the quality of life in remote communities. However, it is difficult to argue that these are areas where investments in S&T should be led by the private sector.

We have taken our sustainable energy mandate to mean the balancing, and where possible, the simultaneous pursuit of positive economic, environmental and social outcomes. Within this context, the primary area of overlap between public and private sector interests is one in which synergies between economic and environmental benefits can be exploited. Social benefits are subsequently those derived from improved economic and environmental outcomes.

With respect to energy security, we did not view concerns about the security of domestic supply, given Canada's status as a major energy exporter, or concerns about the security of the energy infrastructure as major drivers of Canadian energy S&T.

From an economic perspective, priority areas are as follows: areas in which new technologies can address unique and important economic opportunities related to Canada's resource base or geography; areas in which our knowledge or industrial base give us the opportunity to lead the world in the development of new technologies that could have important markets in Canada and internationally; and areas in which incremental investments in S&T in Canada can have a major economic benefit.

From an environmental perspective, priority areas are those in which incremental investments in technology development could substantially reduce the environmental impacts of energy production and use. For example, new technology could minimize the impacts of the energy sector on water and air quality as well as on the integrity of ecosystems.

Perhaps the most significant long-term environmental challenge for the energy sector that we identified is human-induced climate change through the atmospheric release of greenhouse gases (GHG). We note that over 85% of GHG emissions from human sources in Canada are a result of energy production and use; other countries report similar numbers. While Canada makes up only 2% of global emissions, global greenhouse gas emissions will, over time, have to be reduced dramatically to minimize the risk of significant adverse impacts to the Earth's climate. Therefore, the technologies we develop to address domestic GHG emissions may also find significant international markets.

Finally, *the social benefits* consistent with our framework include increased employment due to greater economic activity in the Canadian energy sector, and improved health outcomes due to improved environmental conditions.

We assigned the highest priority to the S&T options that, to the greatest extent possible, simultaneously addressed these economic, environmental and social dimensions, while providing Canada with an opportunity to become a world leader in a given area of energy innovation.

THE PROCESS

The following chapters of the report identify key technology priorities for Canada within an energy-systems approach. As a first step, the suite of energy technologies has been organized into system-specific chapters as follows:

- carbon-based fuels
- renewable and nuclear electricity generation
- fuel cells and hydrogen
- advanced energy end-use

The reasons for choosing these energy systems are provided in each chapter. While not a system in the same sense as the others, fuel cells and hydrogen are considered in the same chapter because of their connections and the fact that they are both relevant to two or more of the major systems defined in the other chapters.

We began our assessment of priorities by conducting a factual review of the economic, environmental, social and technological opportunities and challenges presented by each of the energy technology areas falling within the four systems listed above. This review was complemented by additional research and discussions with experts at our monthly meetings. In addition, candid written input was sought from a broader cross-section of experts in each area. We then assessed the priority of individual technology areas within each system.

Within the above framework, we placed an emphasis on identifying key "platform" technologies whose development could significantly increase the returns of a given energy system. High-priority technologies of this type have been identified as platform technologies throughout the report.

Rather than try to prioritize all technologies, we have singled out those few platform and other technologies that we believe are particularly high priorities for Canadian energy S&T. In addition, we present discussions of all the technology areas considered and make some additional suggestions in specific areas we deemed to be particularly worthy of note.

CHAPTER 5

CARBON-BASED FUELS

Carbon-based fuels include fossil fuels—oil, natural gas, bitumen and coal—as well as biomass. This chapter presents S&T as it relates to the production of carbon-based energy supplies and their conversion into useable heat and energy carriers such as gasoline, electricity and hydrogen.

Canada is fortunate to have some of the largest fossil fuel resources in the world. The oil, gas and coal industries provide baseload electricity and fuel for our transportation needs, and are key inputs into countless products and processes. The export value of these resources is equally important and will continue to garner the attention of both developing and developed nations.

As these industries are linked through their inputs and outputs, fossil fuels may be thought of as parts of a system. This system can be made stronger by employing technologies that improve the economic and environmental viability of each component resource and of the system as a whole. Two such opportunities are discussed as platform technologies at the end of the chapter.

Canada also has significant bioenergy potential. Although bioenergy could be included as part of the discussion on renewable energy, it is incorporated in this section because of the potential synergies between the technologies related to advanced biomass use and those related to fossil fuels.

In line with the recommendations made in Chapter 3, the development of a systems research program concerning carbon-based fuels and involving strong partnerships between industry, government and academia is crucial to optimizing the economic and environmental elements of this energy system.

BIOENERGY

PRIORITY AREA: Bioenergy

Canada has large waste biomass resources and is a leader in a number of bioenergy-related technologies that could be further developed for domestic and international markets. Beyond waste biomass, authoritative life cycle analyses should be conducted to examine the economic and environmental merits of different feedstocks and technology options.

Canada's existing biomass feedstocks come in many forms, such as forest product mill residues, forest floor residues, agricultural residues and municipal solid waste. As an example, a recent survey of Canadian mill wood residues estimated that approximately 3 million tonnes of surplus mill residues (equivalent to 54 PJ) are generated annually by Canadian sawmills; this in addition to 16 million tonnes of existing bark and hog fuel piles. The diffuse distribution of biomass feedstocks often makes them expensive to collect and transport. As a result, bioenergy applications are likely to be localized and targeted, such as in pulp and paper mills and district heating. Even so, technologies to recover and transport biomass more efficiently would improve the availability of the resource and should be actively pursued.

Canadian firms and researchers have world-class bioenergy technologies in areas such as biomass gasification, pyrolysis and cellulosic ethanol production which could be widely applied both domestically and internationally. Gasification of biomass may be of particular interest to a number of applications and is discussed in more detail later in this chapter. In industries where bioenergy may find early applications, such as the forest products industry, it may be necessary to provide early customers with financial assistance to reduce the perceived risk of new bioenergy technologies.

We are optimistic about the near-term prospects of energy generation from waste biomass products. This includes the efficient use of wood waste to generate decentralized electricity, thus taking advantage of a low-cost energy source that generates no greenhouse gas emissions beyond those that would otherwise have occurred through natural decomposition over time. In some regions, co-firing biomass with fossil fuels may make economic and environmental sense, and should be considered as part of an assessment of bioenergy options. Bioenergy from municipal solid waste may also provide economic and environmental benefits.

Beyond waste biomass, there are significant questions about whether bioenergy resources could be economically and environmentally viable. Consequently, authoritative life cycle analyses of the environmental and economic costs and benefits of biomass options should be conducted to examine the merits of the different non-waste biomass alternatives (e.g. energy crops) as well as technology options for non-waste bioenergy.

UNCONVENTIONAL OIL

A large percentage of Canada's proven conventional oil reserves can be extracted using established technologies. Therefore, the focus of this section is on unconventional oil, which we take to include bitumen (i.e., oil sands) and heavy oil.

A number of economic opportunities in unconventional oil could be realized through the development of new technologies. These include moving to improved extraction techniques and replacing high-cost natural gas with lower-cost feedstocks or other energy sources for the production of needed heat and hydrogen. Market forces alone will most likely drive industry to invest in the technology required to capitalize on these opportunities. Therefore, while extremely important, these areas are not seen as key national priorities as defined in Chapter 4.

The oil industry, however, invests relatively little in medium- to long-term technology research in Canada relative to its revenues. This is partly the nature of a commodity business in which much of the innovation is embodied in equipment purchases and in near-term process refinements. However, these actions do little to address long-term sustainability issues or ensure long-term competitiveness. Furthermore, a lack of research investment in Canada by both domestic and multinational companies hinders the development of a large, technologically advanced Canadian equipment supply sector. Mechanisms that encourage private research funding to address common, long-term economic and environmental issues would therefore be of benefit. As discussed in Chapter 3, incentives may take the form of regulations that commit funds for sector-specific R&D, or government co-funding of collaborative industry research targeting long-term objectives.

In addition to increased private sector R&D, certain joint public-private efforts should be encouraged. Collaborative efforts may provide economic benefits, but their primary goal should be to address environmental issues that may hamper the long-term viability of the oil sector. While there are continuing concerns about air and water quality and land management, provincial regulations and collaborative public-private research have been fairly effective in addressing these issues. There are, however, technological solutions that can simultaneously improve environmental and economic outcomes. Gasifying coal or oil sands residues can provide the heat, electricity and hydrogen needed in the oil production process at a lower cost than natural gas. In addition, local pollutants and carbon dioxide can be removed from the input feedstocks. The captured carbon dioxide can then be stored or used for enhanced oil recovery. This approach can improve the economic benefits and reduce the environmental impacts of the fossil fuels sector. Gasification and CO_2 capture and storage are therefore important opportunities related to unconventional oil and are discussed in detail at the end of this chapter.

NATURAL GAS

Natural gas is a versatile and high-quality fuel, used for both heat and electricity generation and as a feedstock in numerous materials processes. As it leaves a smaller environmental footprint than other fossil fuels per unit of energy, it should be used judiciously so that maximum value can be extracted. Techniques for extracting and using conventional natural gas are important but technologically mature. Therefore, they are not priority areas for a national S&T effort. The comments below focus on unconventional gas extraction.

Canadian firms have led in the development of some technologies for the extraction of tight and shale gas and coal bed methane, while other technologies exist internationally and need to be tailored to Canadian circumstances. The industry has begun employing and adapting such technologies and will continue to do so as economic considerations prove them to be viable. The same is generally true of gas extraction technologies for offshore and frontier regions, with the possible exception of offshore technologies in northern locations, where the presence of ice poses new technical challenges to be addressed. As a whole, these are areas in which market forces, coupled with adapting Canadian and international expertise, will likely be sufficient to lead to the implementation of new technologies.

Methane gas hydrates are unlike other forms of unconventional gas because the technologies for their extraction do not yet exist. A gas hydrate is a crystalline solid consisting of gas molecules, each surrounded by a cage of water molecules. It occurs abundantly in nature, both in Arctic regions and in sediments on the deep ocean floor.

Gas hydrates are a unique challenge because Canada has a vast potential resource, but the technology needed to exploit this resource remains in the early stages of development. Given our expertise in this area, there is justification for continued investment in basic research into gas hydrates in partnership with others. However, other countries with fewer energy options, such as Japan, may have more incentive to develop the technologies needed, providing an opportunity to reduce our costs through collaborative research. Gas hydrates is one area that would benefit from dedicated funding targeting basic and applied energy research, as proposed in Chapter 3.

COAL

Coal has always played a significant role in the generation of electricity, and this · expected to grow in a number of jurisdictions as demands for electricity increase. Current coal mining and extraction technologies are well established, and ongoing incremental improvements will be sufficient to overcome cost or supply barriers. Advanced coal technologies are presently aimed at enabling the use of coal for heat, power and chemical production in ways that are environmentally and economically sustainable.

As with unconventional oil technologies, government-industry partnerships should focus on areas that will reduce the environmental footprint of coal utilization. The United States and Germany are leaders in the development and deployment of clean coal technologies, surpassing Canadian efforts in this field. Furthermore, coal-fired power generators in Canada invest very little in clean coal technologies. To develop cleaner, higher-value uses for Canadian coal, we must encourage industry to invest in technology.

That being said, Canada has some research efforts underway in advanced coal technologies such as gasification. Particularly promising are efforts aimed at the end-of-pipe capture of CO_2 from coal-fired power plants, and the adaptation of coal gasification technologies to low-rank Canadian coal.

As is the case for unconventional oil, a unique western Canadian economic and environmental opportunity exists regarding the synergies between coal gasification and the hydrogen/power requirements of the oil sands sector, coupled with CO_2 capture and storage. Exploiting this synergy is our most effective route to deploying clean coal technologies, developing Canadian expertise in the integration of large-scale polygeneration systems, and becoming a world leader in CO_2 management through capture and storage. This opportunity is discussed below.

PLATFORM TECHNOLOGY: GASIFICATION OF CARBON-BASED FUELS

PRIORITY AREA: Gasification

Given Canada's resource base, the development of world-class expertise in the gasification of carbon-based fuels is a high-priority opportunity for Canada. If coupled with CO_2 capture and storage, these technologies will also significantly reduce the environmental footprint of fossil fuel industries.

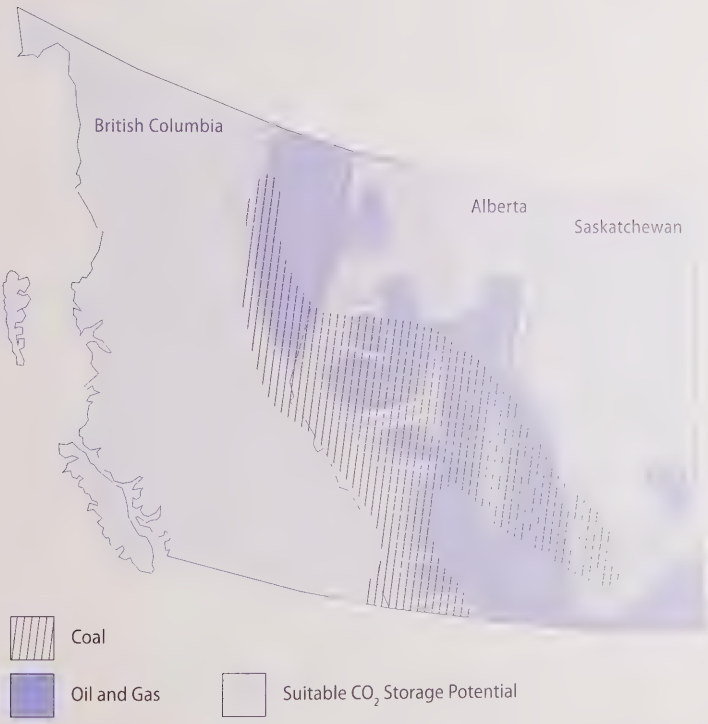
Conventional gasification of carbon-based fuels involves combining these fuels with steam and oxygen under high temperatures and pressures to produce a blend of carbon monoxide and hydrogen. This blend can be used directly or converted into petrochemicals, heat and electricity. The by-products of the process are capture-ready streams of CO_2, particulates and trace metals that would otherwise have been released into the atmosphere if the input fuel had been burned. As such, gasification can have significant environmental benefits over conventional fossil fuel usage if coupled with CO_2 capture and storage.

As mentioned in previous sections, western Canada has all the components necessary for a concerted push towards large-scale hydrocarbon gasification coupled with CO_2 capture and storage:

- There are large volumes of coal available to gasify for power and to polygenerate the hydrogen and petrochemicals that are required by the petroleum and chemical industries in the region. This could increase the value and reduce the environmental footprint of coal and other parts of the fossil fuel sector.
- The oil sands industry currently produces most of the needed hydrogen and heat from high-cost natural gas. The cost of natural gas is motivating the industry to consider alternative technologies such as the gasification of residues and waste products from oil sands production, as well as coal.
- The coal and oil sands supplies in the region sit near sources of demand for hydrogen and petrochemicals and near potential sequestration sites for CO_2.

Figure 7 illustrates how fossil fuel reserves and potential CO_2 sequestration sites align in Western Canada, due mainly to the presence of the Western Canada Sedimentary Basin (WCSB).

FIGURE 7.
Proximity of fossil fuel reserves to suitable CO_2 storage sites.



There is thus an opportunity for government and industry to work together to create a gasification cluster in western Canada that could create and exploit stronger linkages within the fossil fuels sector. Doing so could reduce the environmental footprint of our important fossil fuel resources and increase the economic value of these resources to Canadians. The basic technology necessary for such an effort already exists; however, it requires S&T for scale-up, integration and adaptation to Canadian feedstocks and applications.

In carrying out such a program, Canada would become a world leader in the creation of the soft, system-level intellectual property necessary for large-scale gasification, which could then be coupled to CO_2 capture and geological storage. This technical expertise would be well suited to what may be a growing global market for gasification and CO_2 capture and storage technologies. From a government perspective, the environmental benefits of CO_2 capture and storage from fossil fuels present a compelling reason to encourage the development of a fossil fuel gasification cluster in Canada.

There may be strong synergies between such an effort and smaller-scale biomass gasification, biomass co-firing with other feedstocks, and both large- and small-scale hydrogen production for uses other than those in the oil sector. These connections should be recognized and form an integral part of this effort to develop expertise in the gasification of carbon-based fuels.

PLATFORM TECHNOLOGY: CARBON DIOXIDE CAPTURE AND STORAGE

PRIORITY AREA: CO_2 Capture and Storage

Canada is fortunate to have geographically favourable conditions for storing large amounts of CO_2 near its fossil fuel resources in western Canada. Therefore, there is an opportunity to develop CO_2 capture and storage technologies to increase the environmental sustainability of these important resources. Capture and storage should be strongly linked to any government participation in a fossil-fuel gasification effort.

Canada's fossil fuel endowment is a major economic and geopolitical advantage. However, Canada and the global community are becoming increasingly concerned about the adverse impacts of GHG emissions from the production and use of fossil fuels. The only means of taking advantage of our fossil fuel opportunities while avoiding such impacts is by significantly mitigating the environmental footprint of these fuel sources and, in particular, substantially reducing the greenhouse gas emissions stemming from their production and use.

Canada's geology also presents a unique opportunity to store large amounts of carbon dioxide in the Western Canada Sedimentary Basin with preliminary estimates of storage potential being equivalent to at least 100 years and potentially more than 1,000 years of Canada's current total annual CO_2 emissions. Geological formations in the WCSB, including oil reservoirs and saline aquifers, are likely capable of safely storing carbon dioxide for extremely long periods. In fact, the Intergovernmental Panel on Climate Change suggests in a recent report that CO_2 storage in regions like the WCSB can be done safely in appropriate geological reservoirs with a total leakage of less than 1% over 1,000 years. There may also be some potential for geological storage of CO_2 in other parts of the country where significant amounts of fossil fuels are produced and used.

As shown in Figure 7, the WCSB is located close to major Canadian sources of CO_2 emissions from oil sands production and from coal-fired electricity generation. There are also CO_2-enhanced oil recovery opportunities in the region, which may create an early-stage market incentive for the capture and delivery of CO_2. In addition, the synergies between advanced fossil fuel gasification technologies and CO_2 capture and storage are an important part of cultivating Canadian expertise in large-scale CO_2 sequestration.

Given these factors, Canada should vigorously pursue a program aimed at large-scale CO_2 capture and storage in western Canada. We note that Canada already has significant expertise in the field due to existing activities, such as the International Energy Agency (IEA) Greenhouse Gas Weyburn Monitoring and Storage Project. We must maintain and expand Canadian leadership in this field by exploiting our unique opportunities.

That being said, unlike hydrocarbon gasification, the large-scale capture and storage of CO_2 could be of commercial interest only if there is a long-term commitment by governments to manage greenhouse gases. Major public and private sector investments in this area could become stranded if they are made in the absence of a clear policy message from various levels of government about the nature of Canada's ongoing commitment to GHG reductions. Clear signals are therefore essential if Canada is to capitalize on the opportunity to be a leader in developing large-scale carbon dioxide capture and storage.

With respect to a CO_2 capture and storage effort, there are two distinct aspects worthy of attention and support: CO_2 capture, transport and injection; and management of stored CO_2.

Technologies exist to capture, transport and inject CO_2 into geological reservoirs, but they are in need of larger-scale validation, integration and refinement to be able to store large volumes of CO_2 cost effectively. The siting of CO_2 transportation infrastructure should be guided by system-level assessments of the economic and environmental benefits that may be realized over time. In the presence of long-term signals to guide CO_2 management, industry would define and carry out demonstration projects, with government providing only the incremental support needed to make a project viable.

Responsible management of stored CO_2 requires systematic and transparent assessment of risk arising from leakage of stored CO_2, and the development of tools for identifying and managing storage sites. In addition, there is a need to develop appropriate monitoring protocols and infrastructure. An improved understanding of these variables should contribute to the development of regulations for the safe handling and storage of CO_2 in Canada. Ultimately, it will have to be determined who bears responsibility should stored CO_2 present any risks in the future. Government is best positioned to lead on these issues, and their resolution is a prerequisite to a large-scale storage effort.

CHAPTER 6

RENEWABLE AND NUCLEAR ELECTRICITY GENERATION

Emerging and large-scale renewable energy sources and nuclear power share the property of not directly generating greenhouse gases or other potential atmospheric pollutants during electricity production.

Individually, renewable and nuclear technologies were not considered by the Panel to be key priorities for a national energy S&T effort. This is due to one or more of the following factors, depending on the technology in question: high costs, the relative maturity of the technology area, the lack of Canadian expertise or leadership or the nature of the Canadian resource base. Nevertheless, we have important recommendations on these technologies.

However, when considering the energy sources as a whole, it becomes clear that they all share common issues related to electricity transmission, distribution and storage. These issues can be addressed by building on existing Canadian expertise to the benefit of the electricity system and the public. Thus, advanced electricity transmission, distribution and storage systems are a high-priority technology area for Canada and are discussed in detail at the end of the chapter.

RENEWABLE ENERGY

Renewable energy, which is typically used to produce electricity, can be divided into large and emerging sources, as defined below.

Large Renewable Sources

Large renewable electricity sources include large hydro and wind. Large hydro is a major, well-established electricity source in Canada. While not on the same scale, wind energy is growing rapidly and poised to become a much larger source of electricity in Canada given recent announcements of the development of substantial additional capacity.

Large Hydro

Canada is known for its vast hydropower resources, which are found across the country. Hydro is a well-established and reliable energy source, accounting for 57% of Canadian electricity production.

Science and technology development in hydropower generation should continue, but should be secondary in importance to less mature energy technology areas. It is generally believed that S&T will not significantly alter the current state of hydropower technologies. The focus for S&T activities in hydropower generation should be on specific Canadian issues, such as construction in permafrost regions, cold climate impacts on equipment, and reducing infrastructure costs. In addition, R&D regarding the environmental and social impacts of dam construction could lead to improvements in managing existing hydropower installations and in making decisions on how and where to develop new hydropower resources.

Canada should explore whether hydro systems, with their inherent energy storage capacity, could be more effectively deployed within a "smarter" electricity system: one which uses storage and grid connectivity jointly to enable more efficient integration of diverse sources of electricity, including other forms of renewable energy.

Wind

By virtue of our geography, Canada has a substantial wind resource that could in principle be harnessed on a large scale to supply a significant percentage of the electricity demand in some parts of the country. Currently available technologies make wind a viable option that could have a substantial presence in the electricity system in the coming years.

Given the relative costs and benefits of wind power, we consider this energy source to be a significant part of a future cleaner energy system in Canada. Existing provincial and federal wind deployment and subsidy programs are already making wind power a more substantial part of the electricity mix. The effective deployment of wind resources could be supported by improved wind mapping and forecasting, coupled with techno-economic modeling of the economic viability of our resources. Recently announced initiatives such as the Canadian Wind Atlas and the WindScope tool support the objective of effectively deploying wind power.

Internationally, rapid growth in wind power over the past decade has led to consolidation of the industry around a few major suppliers of wind turbine systems in the U.S. and Europe. Canada is therefore unlikely to become a major player in turbine design and development at this stage in the sector's maturity. Nevertheless, wind technologies are improving and there may be opportunities for Canadian companies in manufacturing components for new generations of large-scale systems, developing off-grid applications and optimizing wind systems in cold climates.

While Canadian opportunities to develop wind power technologies are not substantial enough to make wind a major focus for Canadian R&D, Canadian governments should take a "watch and be ready" approach: Canada should be ready to focus significant funding to support the development of a technology that has a realistic chance of major success in the market.

Emerging Renewable Sources

Emerging renewable electricity technologies are defined here as those that, for various reasons, have a relatively small share of the electricity market in Canada and internationally. While there are opportunities to develop and exploit these renewable energy technologies in Canada, they are not high priorities for focused Canadian energy S&T, either due to the quality of our resources, Canada's technological capacity or the maturity of a given technology. However, solar photovoltaics (PV) may represent a major research opportunity for Canada, as discussed below.

Solar Photovoltaics

The sun is the biggest energy resource available to us. Given the average energy flux from the sun and the theoretical efficiency limit for the conversion of solar energy into electricity, it may one day be possible for solar power to make a substantial contribution to our electricity needs with a small environmental footprint.

Despite significant advances in PV materials over the years, their efficiencies and costs will not make them competitive with alternative sources of on-grid power in the foreseeable future unless there is a major breakthrough in materials science. Supporting structures, power conditioning and energy storage also make up a significant part of the cost of PV systems and affect the cost competitiveness of solar options.

Efficient and economic energy storage options may be required for solar energy to make sense on a larger scale in Canada. There are, however, important cost-effective niche applications for solar PV, particularly in off-grid environments. There may also be other considerations that could favour solar energy in the future on social and environmental grounds.

Canada is not a leader in developing and producing current-generation solar PV technologies. This fact, coupled with the high cost of deployment, leads us to conclude that a major development and deployment push on current solar PV technologies is not warranted in the near future. However, there is a key opportunity for research in this area.

Canada's strengths in nanotechnology and materials science could enable researchers to significantly reduce the cost and increase the efficiency of solar cells. Targeted research aimed at developing breakthrough solar cell materials is warranted, given the size of the potential market and the environmental benefits of this energy source. We therefore recommend research on advanced photovoltaic materials as a priority for targeted research funds, as discussed in Chapter 3.

Small Hydro

There are many promising opportunities in Canada for electricity production from small-scale hydroelectric generation, typically defined as generation sources that are less than 5 MW in size.

From an S&T perspective, the technologies involved are relatively mature, although there are some opportunities for increased efficiency and greater ability to replicate small hydro installations, which would reduce the costs and facilitate deployment.

We note that small hydro is under consideration for the Renewable Power Production Incentive, which is designed to promote increased deployment and encourage more domestic component manufacturers. Regulations in some provinces may have a negative influence on deployment and should be addressed.

The most important technical issues associated with small hydro are grid interconnection and its associated control, maintenance and safety issues, which it shares with other decentralized sources of electricity.

Geothermal electricity

Geothermal electricity generation is not a priority for Canada, given that our geology does not make for widely accessible shallow geothermal resources and we have a number of other more accessible sources of supply. We recognize that some shallow resources in British Columbia are under active investigation.

Canada should maintain sufficient policy and technical capacity so that a "watch and be ready" approach can be taken to developments in large-scale geothermal electricity generation. We noted that the federal government has little capacity to monitor the state of geothermal electricity technologies.

While this section refers only to electricity production, the Panel believes that geothermal heat storage and ground-source heat pumps have significant potential for buildings; these are discussed in Chapter 8.

Ocean Energy

Ocean energy is primarily focused on wave energy, tidal energy or harnessing ocean currents. Ocean energy is generally not considered a major option for Canada. It has limited potential application in northern environments, and major reliability and environmental concerns. In many areas of potential application, the presence of sea ice and icebergs would pose significant problems for the deployment of ocean energy technologies. Connecting small offshore energy generation to the grid would be a significant challenge. From an environmental perspective, there are concerns about the impacts of ocean energy on coastal and marine ecosystems. However, as with geothermal electricity, a watching brief should be maintained.

NUCLEAR ENERGY

Nuclear energy includes both fission and fusion. Canada's current efforts in nuclear power focus on fission technologies. The recommendations below apply to fission, with the exception of the final recommendation concerning fusion.

Nuclear fission is a proven method of producing large-scale baseload electricity with minimal emissions of CO_2 and other atmospheric pollutants. Based on the recent report of the Nuclear Waste Management Organization, we conclude that the nuclear waste issue is technically manageable. We therefore support consideration of the nuclear power option.

Canada is the world's largest producer of uranium. Mined, milled and concentrated in Saskatchewan, uranium is Canada's largest energy export commodity in terms of energy content. There is an opportunity for Canada to add value to this raw resource prior to export through fuel processing, which would increase the economic benefit for Canada.

Canada has developed a unique indigenous nuclear reactor technology, CANDU, and a nuclear engineering and service industry that have competed successfully on the international stage. Construction of new nuclear reactors is under serious consideration in Ontario and has also been mentioned in political statements in developed countries such as the U.S. and Britain. Should developed countries make a strong, long-term commitment to reducing greenhouse gases, nuclear power could be significantly expanded, creating a potentially large domestic and export market for Canadian technologies, expertise and materials.

Atomic Energy of Canada Limited (AECL), a federal Crown corporation, is currently finishing the engineering of the Advanced CANDU Reactor (ACR). AECL is hopeful that the first unit could provide power in the next decade. At this late stage in its development, we believe that political and market factors will determine the fate of the ACR.

With regard to nuclear power S&T, Canada has signed on to the collaborative international effort to develop fourth-generation nuclear technologies (by about 2030) known as Generation IV. While future generation nuclear technology gives Canada an opportunity to build on its existing nuclear capacity, we note that S&T for the development of new reactors is costly. Active Canadian participation to develop and benefit significantly from a new class of reactor could require large investments for up to 20 years or longer. Because of this reality and the wide range of factors that must be considered when assessing the potential benefits of developing fourth-generation nuclear technologies in Canada, we do not feel equipped to make a recommendation on whether a key energy S&T priority for Canada should be to go ahead with this next round of reactor R&D. In our view, a dedicated independent review of next generation Canadian nuclear S&T is warranted. Such a review should include assessments of:

- the rationale and expected costs and benefits of developing GEN IV technology, including:

  - the investments needed for Canada to be fully involved in the development, construction and commercialization of fourth-generation nuclear reactors;
  - the likelihood of success of the GEN IV initiative, in particular, the Supercritical Water-Cooled reactor design which is most closely aligned with Canada's existing nuclear expertise and would likely be the focus of Canada's GEN IV efforts;
  - the likely domestic and international market for Canadian nuclear technology and services within a successful GEN IV design, and therefore the economic benefit we might reasonably expect from our investment.
- the best role for the federal government in supporting next-generation reactor design, taking into consideration the potential for AECL to invest in the initiative through its own current and future revenues.
- the trade-offs involved in dedicating resources to S&T versus investing comparable funds in other promising energy technologies.

We emphasize the last point, as we feel that decisions on government investments in nuclear energy S&T should not be separated from other energy S&T investment opportunities, as is currently the case in Canada.

Should the federal government find that continued or increased nuclear S&T funding is the right choice, investments should be guaranteed over a period of several years subject to meeting agreed milestones. In major multi-year projects such as nuclear reactor development, annual funding decisions create planning uncertainty, which can lead to inefficient resource allocation and an erosion of the necessary human resources.

Finally, regarding nuclear fusion, Canada abandoned its nuclear fusion program in the 1990s. To keep Canada's options open, a university-based research program should be created to develop and maintain some expertise in this area and monitor international developments. In this way, the sector could be revived in the future should Canada wish to reconsider active participation in the development of fusion power technologies.

PLATFORM TECHNOLOGY: ADVANCED ELECTRICITY TRANSMISSION, DISTRIBUTION AND STORAGE SYSTEMS

PRIORITY AREA: Electricity Transmission, Distribution & Storage

We believe that making the best use of Canada's wealth of electricity-generating resources will require a focus on developing and deploying technologies to optimize electricity transmission, distribution and storage. Unique Canadian challenges brought on by a combination of issues associated with infrastructure, the intermittency of renewable sources, impacts of weather and increasing expectations for quality power, to name but a few, must be addressed. Doing so would increase the benefits derived from existing electricity resources and greatly improve the grid access for a variety of emerging energy options. This is an important technology area in which Canada can build on a strong existing base of expertise. A critical element for success in this area will be stronger cooperation and coordination among the provinces and the federal government in the planning, R&D and deployment of electricity transmission, distribution and storage technologies.

The success and prosperity of our industries, businesses and communities depends on a stable and secure supply of electricity. Canada is fortunate to have considerable human, natural and physical capital relevant to electricity generation, transmission and distribution.

The transmission and distribution (T&D) infrastructure is a complex system that is essential for a reliable electricity supply. New technologies can reduce costs and increase performance and reliability by enabling the safer, more efficient delivery of electricity and the more effective utilization of electricity generation sources. Looking to the future, smart transmission and distribution systems coupled with energy storage will be key to the safe and efficient integration of distributed generation and electricity from intermittent renewable resources.

Canada's T&D system is aging and will require considerable upgrading and refurbishing. In addition, commercial, industrial and consumer demand for high-quality electrical power is increasing. These factors present timely opportunities to employ new technologies that would enhance the reliability and functionality of existing electricity T&D assets. New technologies would also enable the country to address the continued growth in electricity demand while meeting increasingly complex quality and safety requirements.

Given these considerations, we feel that there are three areas that warrant a concerted Canadian focus:

- smart electricity transmission and control technologies, which would facilitate the optimal deployment of baseload, peaking and intermittent sources of electricity as well as distributed sources of generation, while increasing overall power quality;
- control technologies for the safe integration of decentralized energy sources, including renewables into the grid while simultaneously allowing for higher system capacity; and
- electricity storage technologies that could reduce electricity system vulnerability, increase reliability, and permit the economic integration of intermittent renewable energy sources.

International and interprovincial boundaries act as unnecessary disincentives to the development and implementation of advanced T&D technologies, and reduce the ability to use the Canadian electricity system in the most environmentally and economically efficient manner. Greater integration and optimization should be strongly encouraged where there are compelling justifications for doing so on the grounds of enhanced supply, system stability and economic and environmental benefits.

Renewal of the electricity system will require specialized human capital that is today diminishing at an appreciable rate, in part due to the low level of public and private sector investment in this area in recent years. For example, the electricity industry in Canada currently invests only 0.59% of its revenues in research.

As an important step towards realizing greater benefits from our electricity resources and developing our human capacity in the field, we recommend that the federal government work with provincial governments to create an energy systems research institute with an emphasis on electric power systems engineering, in line with the recommendation on energy systems research in Chapter 3. The mandate of this program should be to:

- identify how best to utilize existing electricity resources across North American T&D systems to optimize their benefits to Canadians;
- identify opportunities for new energy generation technologies and infrastructure that would address reliability, cost and environmental integrity; and
- develop intelligent systems technologies and analysis tools that could improve our ability to efficiently utilize various energy sources including intermittent renewables in commercially viable systems.

We recognize that most of the capacity and jurisdiction for such an effort lies with the provinces. However, we believe that the federal government could play an important role in helping key utilities and research institutions establish such a program, and could provide a significant percentage of the investment required in such a worthwhile effort.

A coordinated effort is a real possibility in Canada, given the relatively few actors involved in electricity transmission and distribution. While governments are key actors, the success of such an institute would also require the full participation of the relevant power generators, utilities regulators, electricity-related industries and the academic community to provide intellectual and financial resources as well as detailed data about the Canadian electricity system.

CHAPTER 7

FUEL CELLS AND HYDROGEN

Fuel cell and hydrogen technologies are relevant to many of the energy systems described earlier in this report, and there are some important areas in which their interests overlap. However, the scope of applications for each is much broader than the hydrogen-powered fuel cell car that often comes to mind.

Fuel cells promise higher-efficiency mobile, hand-held and stationary power and will succeed on their ability to meet market demands and environmental needs in these areas. Hydrogen can be used as an energy carrier and as an input to many chemical processes. The widespread use of hydrogen as an energy carrier would represent a fundamental change in the way we use energy and impact the environment.

FUEL CELLS

> **PRIORITY AREA:** Fuel Cells
>
> **Canada has a world-leading position in many fuel cell technologies, due in large part to first-class expertise operating within a strong and vibrant innovative cluster of companies and institutions. Retaining and further extending our leadership position in this knowledge-based sector is critical if we are to capitalize on this increasingly competitive and growing market.**

We are impressed by the vibrancy, technical expertise and entrepreneurial spirit of the Canadian fuel cells cluster. For example, the Vancouver hydrogen and fuel cells community boasts innovative companies that are developing novel fuel cell technologies for the portable, stationary and transportation markets. Other clusters of expertise exist in Alberta, Ontario and Quebec. In our view, Canada maintains a world-leading position in proton exchange membrane fuel cell technologies, which it can build on to supply what is likely to be a growing global market. Canada also boasts expertise in fuel cell systems integration. As a whole, the fuel cells and associated hydrogen sector is a major performer of energy R&D, investing over $200 million annually, mostly from private sources.

We note that fuel cells are an early-stage, knowledge-based sector that is heterogeneous with respect to its products and stages of product development. This situation is in contrast to parts of the energy economy which use technologies to produce a commodity product; this fact should be reflected in the funding mechanisms within this sector. In particular, funding mechanisms may need to be more in line with those in other knowledge-based sectors, such as information and communications technologies and biotechnology, than with those traditionally used in other parts of the energy economy. Research and development, supported by government and private equity, is and will continue to be particularly important for this sector. The energy venture fund proposed in Chapter 3 may be a promising vehicle for providing the further investment needed for the sector's success.

In the near term, some companies are capitalizing on existing fuel cell technologies in niche markets, such as specialized vehicles and hand-held power applications. However, it would appear that the market prospects of many fuel cell technologies are longer term and contingent on significant additional technological development. In these cases, resources should be devoted more to basic research than to later-stage S&T, to which most government support to date has been directed; of the $215 million allocated by the federal government to hydrogen and fuel cells S&T in 2003, $195 million targeted activities related to near-term deployment and commercialization. Future government funding should better reflect the actual needs within the sector, as defined in consultation with industrial stakeholders.

In this vein, the Panel notes the importance of the on-road fuel cell vehicle (FCV) effort in attracting investment and expertise to the fuel cells sector. However, there are questions about the near-term promise of commercial on-road fuel cell vehicles. It is clear that FCV technology has made considerable progress over the past five years. Still, significant technical barriers — relating to fuel cell performance, durability and cost and to on-board hydrogen production or storage — must be overcome. These areas could benefit from targeted funding for early stage research, as discussed in Chapter 3. It may in fact be useful for the sector to make a stronger distinction between the ambitious FCV effort and other fuel cell technologies that may have much clearer near-term prospects.

Finally, we recognize that there are a number of companies and laboratories in Canada doing innovative research into battery technologies which may compete with or complement some fuel cell applications. Support should be available for promising battery technologies that emerge, but batteries are not viewed as a high S&T priority, since the dominant research expertise in this area is located outside Canada.

HYDROGEN PRODUCTION, STORAGE AND DISTRIBUTION

Hydrogen is a versatile chemical element which reacts with most other elements and is part of countless chemical compounds. It can be produced from a number of primary energy sources, from the electrolysis of water or as a by-product of some chemical processes. While it is the most abundant element in the universe, hydrogen is difficult to produce in large quantities by itself. When combined with oxygen, it can be used to produce useful energy with virtually no atmospheric pollutants at the point of use. The production, transportation and storage of hydrogen involve technologies relevant to a number of high-priority areas that we have identified, such as gasification, CO_2 capture and storage, and electricity storage.

Currently, the major uses of hydrogen are in the oil and chemical industries. Existing hydrogen production methods for these purposes result in significant CO_2 emissions. Significant advances in a number of areas relating to hydrogen production are needed to make hydrogen fuel cells viable options for on-road vehicle applications. However, just as fuel cells can use fuels other than hydrogen, hydrogen may find future uses in areas other than fuel cell vehicles, including internal combustion engines, freight transport and aviation. We emphasize, however, that the large-scale use of hydrogen as the energy source for transportation would represent a profound shift in our energy infrastructure.

Basic research into transformative hydrogen technologies related to production and storage are important to realizing hydrogen's promise of enabling the storage and use of energy without harmful life cycle emissions. Economic, environmentally friendly hydrogen production could potentially be accomplished through:

- the production of hydrogen from fossil fuels by such methods as gasification, coupled with the geological storage of the resulting carbon dioxide, or the gasification of waste biomass;
- technologies that significantly improve the economics and efficiency of producing hydrogen from water using electricity sources that do not emit CO_2; and

- the development of novel technologies for hydrogen production, such as direct hydrogen production from water using sunlight, and biological processes that decompose organic materials into hydrogen and other by-products.

The first option above is one element of the need for a Canadian focus on fossil fuel gasification and CO_2 capture and storage in western Canada, as described in Chapter 5 "Carbon-Based Fuels." The latter two options for hydrogen production are less geographically specific and are worthy of targeted funds for early-stage research, as discussed in Chapter 3.

Canada has a world-leading position in current-generation mobile and hand-held hydrogen storage technologies. That being said, there are still many challenges to storing hydrogen for on-board, mobile applications. For on-road hydrogen fuel cell vehicles to compete with other advanced vehicle technologies and provide substantial environmental benefits, a breakthrough in high-density, low-weight, low-cost hydrogen storage is required. This is also an area worthy of targeted basic research.

Not to be ignored is the importance of large-scale hydrogen production and management to the oil sector. This sector will experience large growth and require more hydrogen, using both mature production technologies and newer technologies as they emerge. Canada has well-established hydrogen distribution expertise and thus has an opportunity to gain more experience with hydrogen infrastructure for advanced applications, including the development of codes and standards for hydrogen distribution and refuelling.

Finally, there is roughly 200 kt per year of unused hydrogen produced in industrial processes in Canada; in energy terms this is equivalent to approximately 800 million litres of gasoline. Identifying increased opportunities to use this hydrogen on site in advanced applications such as fuel cell and hydrogen internal combustion engines would provide opportunities to test such applications in real-world settings. If the hydrogen were used to substitute for carbon-based fuels in these regions, it would also reduce environmental impacts.

CHAPTER 8
ADVANCED ENERGY END-USE

How energy commodities are used is as important as how they are produced and transmitted. Canadians use energy in homes and buildings, industry and transportation. The science and technology behind the structures, systems, services and equipment found in the end-use sectors is crucial to ensuring Canadians use energy wisely.

The end-use sectors tend to consist of diffuse technologies, and heterogeneous users who face social, economic and regulatory barriers to the adoption of new technologies. Therefore, S&T in the end-use sectors should focus in large part on providing consumers with the best information possible and ensuring the adoption of existing technologies that improve both economic and environmental outcomes. Activities include focusing research efforts on areas that are likely to have the biggest impact on energy use, working to better understand barriers to adoption, and ensuring that information about the benefits of new technologies is effectively communicated to the public.

There is great potential for S&T in energy end-use to help Canada meet the environmental and economic objectives described in Chapter 4. However, the wide variety of technologies, opportunities, barriers and players involved in energy use make it difficult to point to particular technologies that might have the best returns for Canadians.

We note, however, that human behaviour and its relationship to technology adoption in the end-use sectors is critical, yet poorly understood. There is a requirement for applied social science aimed at better understanding how humans interact with technology and how they make decisions regarding energy use and technology. We have therefore developed a priority recommendation on this subject, which is described in more detail at the end of the chapter.

COMMUNITIES

Community infrastructure includes buildings, transportation systems, heat and electricity systems, and energy-using equipment. How we design, build and rebuild our communities can have a large impact on our collective energy use. Energy use in communities depends on how individual component services in a community are designed and how the components and systems work together when individual users make decisions every day. In Canadian communities, the most promising methods of reducing energy use are known, such as district heating and combined heat and power systems.

The focus at the community level should be on communication, education and other supporting mechanisms to ensure that the public knows about up-to-date technologies and practices, and can make better-informed choices.

Recommendations that are more specific to buildings, industry and transportation systems are included in their respective sections below.

BUILDINGS

The buildings sector is important to Canadians. We spend the majority of our time in buildings, be they commercial, institutional or residential, accounting for over 31% of total energy used in Canada.

Many technologies already exist that can cost-effectively improve energy use in the buildings sector, but they are not often adopted. Options include improved controls, materials, design and equipment for homes and commercial buildings. Two examples of such technologies are solar heating (active and passive) and ground-source heat pumps, which could be deployed for buildings and homes in a number of regions of the country, in order to reduce costs and increase environmental performance. The potential benefit of using these technologies is high; the real challenge is overcoming the barriers to implementation.

To encourage the implementation of existing technologies, we recommend the development of a framework that encourages the adoption of these technologies through codes, regulation, incentives and education. Its parameters should include three key items. First, it should include a means of disseminating information among decision-makers such as builders, architects, owners and tenants, in order to showcase the successes of energy technologies and practices. Life-cycle analyses and other information aimed at better informing decision-makers would be a key part of this work. Second, it should include educating trades and professions on the importance of energy efficiency. Finally, the framework should recognize that, ultimately, regulations like appliance standards and building codes should reflect the life-cycle costs of technologies and encourage energy efficiency actions. Regulations should also change over time to respond to evolving technologies and practices.

Even with the difficulty of deploying existing building technologies, we believe there should be a substantial increase in funding for energy S&T in the building sector, given the potential opportunity for more efficient energy use. Factoring out investments in programs that encourage energy efficiency, there is currently relatively little spending in this area — roughly $10 million a year; additional resources could lead to substantial energy reductions through the development of more cost-effective and easily implementable technologies. Experts should determine where funds would best be spent, but we suggest that the following areas would benefit from some focus: testing and development of new technologies; monitoring and assessment of advanced technologies and systems in actual user applications; cold climate technologies that are well suited to Canadian circumstances; and developing efficient technologies that can be seamlessly integrated into existing building systems.

Demonstration is also an important tool for encouraging the adoption of efficient energy technologies in Canadian buildings. Demonstrations should be used as a means of communicating with the industry and users about successful new technologies, new uses for existing technologies, and the successful scale-up of technologies. As discussed in Chapter 3, demonstrations should avoid being a showcase for technologies that have little chance of being successfully implemented commercially.

INDUSTRY

The industrial sectors are extremely important to the Canadian economy. Sectors including mining, metallurgy, pulp and paper, and manufacturing are responsible for 38% of energy use in Canada. Most of this energy is consumed by a small number of energy-intensive sub-sectors. The energy-use profiles and technology needs of industrial users vary, although there are some generic technologies, such as motors, lighting and optimization tools that identify recoverable low-temperature heat, that are applicable in all industrial sectors.

Because Canadian industry is so heterogeneous, we cannot take a one-size-fits-all approach to technology adoption. The focus of our S&T efforts should be on the particular sub-sectors that are most important to Canada, and the technologies and processes that can increase their energy efficiency. Needed are appropriate metrics for determining areas of focus, which could include the relative importance to the Canadian economy, and the sectors where S&T will have the greatest potential for benefit.

A number of technologies and energy optimization activities exist and are ready for implementation, but are not adopted because the required rates of return are very high for new projects in energy-intensive companies. There are also inherent risks in changing from a known practice to an unfamiliar one, especially where competitiveness and continuous production are so important.

Policies and investments to improve the energy efficiency of industrial sectors remain important given their large impact on total energy use, but they should be focused on adoption and implementation. Along with regulation or codes, implementation-focused investment may provide the market-pull/technology-push combination needed to help Canadian industry continue to improve its energy efficiency and environmental performance.

In those sectors where energy use is particularly high, a focused effort to find viable S&T solutions could have a significant positive impact. There are a number of existing industry-sponsored research groups and private-public cooperative organizations such as the Canadian Industry Program for Energy Conservation (CIPEC), which could be used as vehicles for greater emphasis and investment in targeted research in industrial energy use.

TRANSPORTATION

The transportation sector is responsible for 28% of energy used in Canada, and includes rail, marine, air and road transportation.

The Canadian transportation sector has traditionally been an adapter and adopter of international transportation S&T, and this is unlikely to change overall. Canada's focus should be on identifying strong niche sectors where Canadians can contribute to the general improvement in energy efficiency and emissions reductions in the field of transportation.

A particularly promising focus area for Canada is freight transportation, including rail, marine and road. In Canada, freight accounts for 40% of transportation energy use (compared with 30% in the U.S.), and energy use in the freight sector is growing faster than in the passenger and off-road sectors. In addition, Canada's geography poses unique challenges of scale and scope for the transportation of goods both domestically and across our borders. Finally, freight transportation can have large impacts on local environmental quality. Canadians have expertise in materials science and engineering which could be applied to freight vehicles. Similarly, Canadian expertise in aerospace and in advanced materials could form the basis for increased S&T activity relating to energy use in air transportation.

In the transportation sector as whole, government transportation programs appear to be largely fragmented and spread thinly. They may benefit from a review, rationalization and focus in a very small number of key areas, that should include freight transportation. Given the size, importance and leadership position of U.S. transportation programs, it would be beneficial if Canadian initiatives and programs were strongly integrated with those in the U.S. to minimize duplication, better leverage our efforts and define areas worthy of Canadian focus.

ADVANCED END-USE PLATFORM: APPLIED SOCIAL SCIENCE

PRIORITY AREA: Applied Social Science

The development and deployment of new and innovative end-use technologies often face many barriers, with social barriers frequently being as compelling as technical and economic ones. A better understanding of these social considerations would help improve the likelihood of implementing new energy technologies, guide policy development and assist in better energy S&T program delivery. We recommend that a major research program be launched in applied social science, aimed at better understanding people's decisions on energy related end-use technology purchases and on their subsequent use patterns.

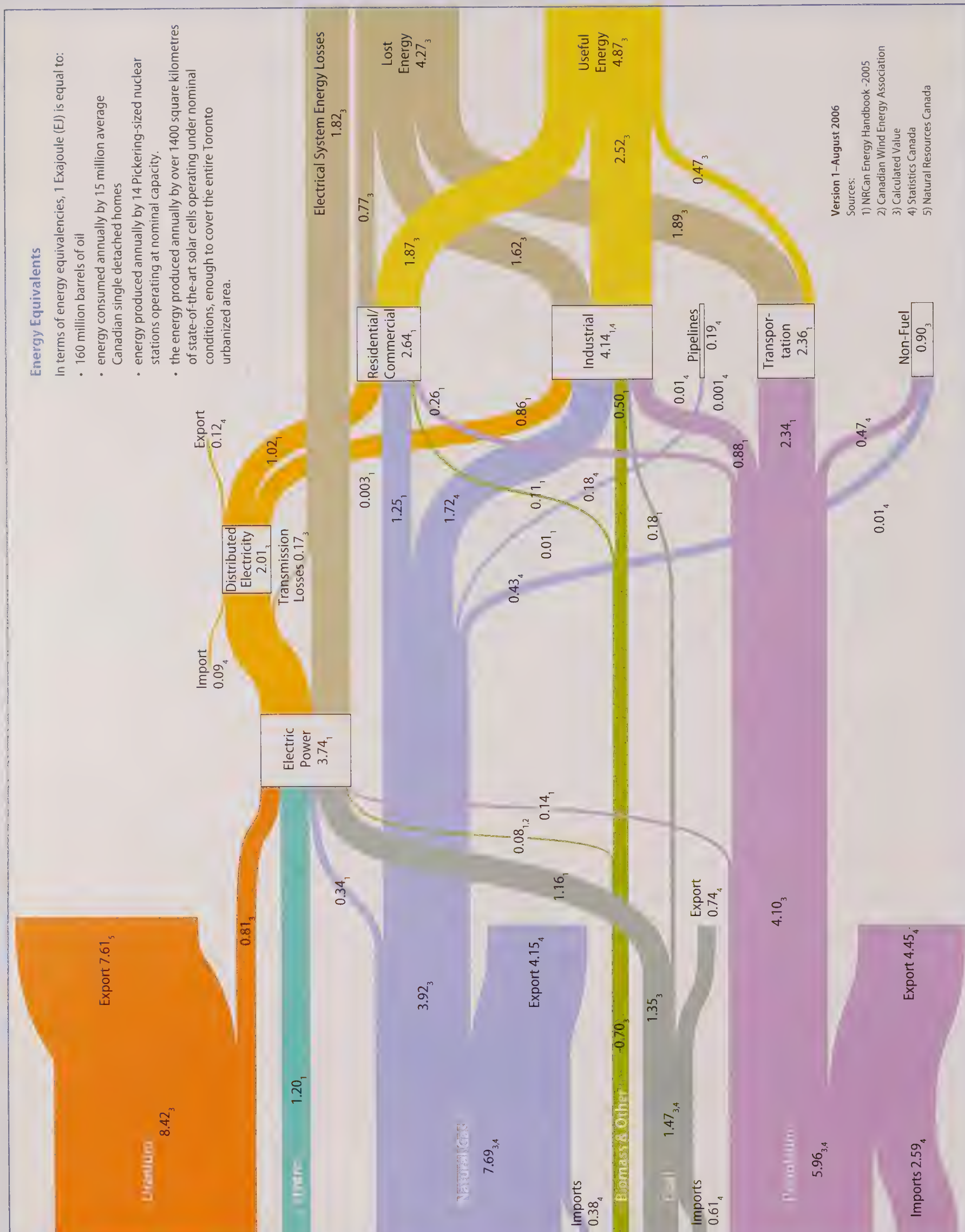
Exploring the human dimensions of energy use in Canada would shed light on why energy efficiency investments are much lower than is rationally justified. Ultimately, a better understanding of human behaviour regarding technology adoption and use would support all efforts to develop and implement energy efficiency S&T, from early applied research to demonstration and deployment programs.

Applied social science regarding energy efficiency is relevant to buildings, communities, transportation and industrial end-use. System-level thinking about end-use could help identify common issues to be addressed in various sectors. There are many possible areas for exploration, including studying decision-making in commercial buildings with complex owner-tenant relationships, analyzing life-cycle costs of new technology choices, understanding the perception of risk among decision-makers in the end-use sectors, exploring barriers that prevent Canadians from increasing their use of waste as a valuable source of energy, and examining technology adoption at the community level, to name a few.

We note that there are many decision-makers involved in end-use sectors, such as the owner, financier, operator, tenant and regulator in the building sector. With so many possible actors who must all support technology adoption, the social aspects of end-use energy technologies are of fundamental importance.

Canadians will continue to make a large number of decisions about small and large energy related investments in the future. Greater social knowledge will enable a more transparent public debate on our energy choices and their potential impacts. Understanding which factors influence our decisions is a key step towards an effective public role in supporting sound decisions on energy technologies that will benefit us all individually and collectively.

CANADA'S ENERGY FLOW – 2003 (units in exajoules)



BIOGRAPHIES

Angus Bruneau (Chair)

In 1987, Dr. Angus Bruneau established Fortis Inc., the parent company of Newfoundland Power. He is currently Board Chair. Dr. Bruneau is a founding Member of the Natural Sciences and Engineering Research Council of Canada (1978–83, 1995–2002) and is a former professor and founding Dean of Engineering at Memorial University of Newfoundland. Dr. Bruneau is a Director of Petro-Canada, SNC-Lavalin Group Inc., Inco Ltd., the Canadian Institute of Child Health, the Canadian Foundation for Innovation and Sustainable Development Technology Canada. He is a Fellow of the Engineering Institute of Canada, the Canadian Academy of Engineering and the Arctic Institute of North America. He is an Officer of the Order of Canada and has been honoured as a Gold Medal Recipient by the Canadian Council of Professional Engineers. Dr. Bruneau holds a PhD from the University of London and honorary Doctor of Engineering degrees from Memorial University of Newfoundland and Dalhousie University.

Denis Connor

Dr. Denis Connor is the Chairman of QuestAir Technologies Inc. which develops and manufactures purification equipment for hydrogen and other gases. He was the founding President and CEO of QuestAir from 1998 until 2002. He is a Director of Angstrom Power Inc., a micro fuel-cell company, having served as the President and CEO from 2003 to 2005. Prior to joining QuestAir, he headed the Science Council of British Columbia for two years and subsequently began consulting to technology start-ups and serving on the boards of a number of such companies. Early in his career, he worked at Bell Laboratories of AT&T and at Northern Telecom's research labs. He joined MacDonald Dettwiler and Associates Ltd. in 1976 where he spent 12 years in various executive positions. Dr. Connor is a professional engineer and holds a Ph.D. in Electrical Engineering from the University of British Columbia. He is a member of the Premier's Technology Council, an advisory group to the Premier of British Columbia.

John C. Fox

John C. Fox is the Managing Director of Perseus, LLC. Previously, he held several positions at Ontario Hydro, including Chief Operating Officer of the Ontario Power Generation Company. He has served in a number of engineering, managerial and consulting positions during his 30-year career. Mr. Fox headed the Energy Efficiency Task Force of President Bush's Commission on Environmental Quality. He is Director of the Alliance to Save Energy, Beacon Energy Corporation, NxtPhase T&D Corporation, Soft Switching Technologies, Incorporated, Serveron Corporation, Nexus EnergyGuide, Incorporated and Puralube, Incorporated, and is Trustee of the Clean Power Operating Trust. Mr. Fox also has served on the Electricity Restructuring AdvisoryCommittee in Costa Rica (Chairman), the American Council for an Energy Efficient Economy (Director), the Business Council for Sustainable Development (Associate Member), the Ontario Roundtable on Environment and Economy and the Environmental Protection Agency's Acid Rain Advisory Committee in the United States.

Daniel Kammen

Professor Kammen is the Class of 1935 Distinguished Chair in Energy at the University of California, Berkeley, where he holds appointments in the Energy and Resources Group, the Goldman School of Public Policy and the Department of Nuclear Engineering. He is the Co-Director of the Berkeley Institute of the Environment, as well as the founding Director of the Renewable and Appropriate Energy Laboratory at Berkeley (RAEL). Dr. Kammen's work focuses on renewable energy science and engineering, energy efficiency, national and international energy policy, international climate debates, and the use and impacts of energy sources and technologies on development, particularly in Africa and Latin America. He is the author of over 200 research and policy papers, as well as the book Should We Risk It? He is a frequent commentator in the media on energy and environmental issues. Dr. Kammen received his undergraduate degree in Physics from Cornell University (1984) and his master's and doctorate degrees in Physics from Harvard University (1986 and 1988). He serves on the board of the Utility Reform Network and the Technical Review Board of the Global Environment Facility. He also serves as a technical advisor to the Union of Concerned Scientists and is a Permanent Fellow of the African Academy of Sciences.

David Keith

Professor Keith works on crosscutting problems related to energy technology and climate change. He has worked extensively on the capture and storage of carbon dioxide (CO_2), including technical work on managing the risks of geologic storage, and serves as chair of a crosscutting group for the Intergovernmental Panel on Climate Change. Dr. Keith serves as a member of several advisory boards and panels including the InterAcademy Council study on *Transitions to Sustainable Energy Systems*, and as member of US National Academy committees. His broader climate and energy-related research addresses the economics and climatic impacts of large-scale wind power, the use of hydrogen as a transportation fuel, and the technology and implications of geoengineering. Dr. Keith has addressed technical audiences with articles in *Science* and *Nature*, he has consulted for national governments, industry and environmental groups, and has reached the public through U.S. and Canadian radio and television. Dr. Keith returned to Canada in 2004 to take a position at the University of Calgary, where leads a research group on energy and environmental systems.

Patrick Lamarre

Patrick Lamarre is the President and CEO of SNC-Lavalin Nuclear Inc. (formerly Canatom NPM Inc.), a member of the SNC-Lavalin Group of Companies. He joined Canatom in 2004. Mr. Lamarre is a chemical engineer with more than 11 years of experience in the industry. His experience covers project financing, operation management, project design, engineering and participation in large projects with a total worth of over $1 billion. Mr. Lamarre joined SNC-Lavalin in 1995 and has worked in Montreal and Toronto, as well as on projects in Chile, Cuba, Venezuela and Australia.

Jacques G. Martel

Jacques G. Martel is currently the Managing Director of the Institut de recherche d'Hydro-Québec and Chairman of the Board of OURANOS, a Quebec-based consortium on climate change and adaptation. Dr. Martel has held the positions of Manager, Technology Development at Hydro-Québec, General Manager of a venture capital fund (Énergie Capital Innovation), Director General of the Industrial Materials Institute (National Research Council of Canada), Vice-President and Technical General Manager of SNC Research Corporation, a subsidiary of Montréal's SNC-Lavalin engineering firm, and Director of the INRSÉnergie research centre, a university-related centre for education and research in the field of energy and materials. Dr. Martel has a Ph.D in nuclear engineering from the Massachusetts Institute of Technology and a degree in engineering physics from *École Polytechnique de Montréal*. He has also taken courses in innovation management from the California Institute of Technology. He is a member of the *Ordre des ingénieurs du Québec*.

Ken McCready

Ken McCready serves as Senior Policy Advisor to the Energy Council of Canada. He has had a long career in conventional energy, alternative energy and large project development — most recently in his roles with biomass energy start-up companies and earlier as President and CEO of TransAlta Corporation. He is Director of EnCana Corporation, Computer Modelling Group Ltd., Biosphere Technologies Inc., and Chairman of Nexterra Energy Corp. In addition, he serves as Chair, Natural Resources Canada Advisory Board on Energy Science and Technology and as a member of the Federal Minister's Advisory Council on Science and Technology. Mr. McCready's previous positions include: Chair, Alberta Round Table on the Environment and the Economy, Chair, Conference Board of Canada, Member, Asea Brown Boveri, Environment Advisory Board, Dow Chemical Corporate Environment Advisory Council, and the World Business Council for Sustainable Development.

Patrice Merrin Best

Patrice Merrin Best is President and CEO of Luscar Ltd., Canada's largest producer of thermal coal and an industry leader in safety and productivity. Luscar is actively engaged in innovative applied research in new clean coal technologies. Prior to joining Luscar, which is owned by subsidiaries of the Ontario Teachers' Pension Plan Board and Sherritt International Corporation, Ms. Merrin Best had been an officer of Sherritt since 1994 and served as its Executive Vice-President and COO from 1999 to 2004. She is a member of the National Round Table on the Environment and the Economy, a Director of the Alberta Energy Research Institute, the Chair of Energy INet, and a member of the Coal Industry Advisory Board of the International Energy Association.

Laurier L. Schramm

Dr. Laurier L. Schramm is President and CEO of the Saskatchewan Research Council. His previous positions include serving as Vice President, Energy with the Alberta Research Council, and as President and CEO of the Petroleum Recovery Institute. In addition to corporate management and leadership, he has over 25 years of R&D experience in colloid, interface, and as petroleum science, has received major national awards for his research, and is known for basic and applied research involving petroleum industry applications of suspensions, emulsions, foams, and surfactants. He has substantial R&D management experience, remains an active full Adjunct Professor, and has taught academic and industrial courses in his field, both domestically and internationally. He holds 17 patents, has published eight books, over 300 other scientific publications and proprietary reports, and has given over 130 national and international, plenary, invited, and other scientific presentations. Many of his inventions have been adopted into commercial practice.